CANADIAN JOURNAL OF
AGRICULTURAL SCIENCE

(*formerly* Scientific Agriculture)

VOLUME 35 NOVEMBER-DECEMBER 1955 No. 6

THE RELATIONSHIP OF MEALINESS IN COOKED POTATOES TO CERTAIN MICROSCOPIC OBSERVATIONS OF THE RAW AND COOKED PRODUCT[1]

A. L. Shewfelt, D. R. Brown and K. D. Troop

Canada Department of Agriculture, Morden, Manitoba

[Received for publication May 26, 1955]

ABSTRACT

A study was made of relationships between mealiness and certain microscopic observations of five potato varieties grown at four different locations in a single season. The results indicated that several factors in addition to specific gravity of tubers were related to mealiness of cooked potatoes. Such factors included the size of the raw starch granules, the thickness of the cooked cell walls, and the ability of the potato cells to retain their entity following swelling and gelatinization of the starch.

Varieties differed significantly in their mealiness rating, raw granule diameter, and in the condition, fragmentation, and wall thickness of the cooked cells. Tubers from different locations varied in mealiness and in cooked cell wall thickness. Canso and Netted Gem exceeded Manota and Irish Cobbler in mealiness, raw granule diameter, and in cell condition and fragmentation ratings. These two varieties also had thinner cell walls. Warba was rated lowest in mealiness and in cell condition and fragmentation. It had smallest raw granule size and thickest cooked cell walls.

Texture ratings were correlated significantly with specific gravity, raw granule diameter, and condition, fragmentation, and wall thickness of the cooked cells.

INTRODUCTION

The cooking quality of potatoes is associated largely with mealiness, sloughing, colour, and flavour. Of these, mealiness is the most variable factor and its variability is responsible in part for the decreasing consumption of potatoes.

Most investigators of potato cooking quality have found a relationship between mealiness and starch content. As a result, specific gravity measurements have become a common practice in the selection and separation of superior quality tubers. The extent of the relationship between mealiness and specific gravity is subject to considerable variation. According to a review by Nylund and Poivan (3), it is influenced by such factors as location, type of growing season, maturity, variety, and storage conditions. They found that potato tubers of the same specific gravity but grown at different locations exhibited differences as large as those between tubers of different specific gravities grown at one location. They concluded that specific gravity alone could not safely be used as a criterion of the texture quality of mealiness.

[1] Contribution No. 848 from the Division of Horticulture, Experimental Farms Service.

A number of workers have suggested that mealiness is associated with cell separation during cooking and hence influenced by the nature of the intercellular pectic substances. The investigations of Freeman and Ritchie (2) however, have shown that cell separation is not necessarily closely related to mealiness. This finding is confirmed in recent studies by Reeve (4) in which cell separation, held responsible for tissue sloughing, is not considered a necessary distinction between mealy and non-mealy potatoes.

Briant (1) studied the physical properties of starch from potatoes of different culinary quality and found a significant inverse correlation between mealiness and the percentage granules below 0.02 mm. in diameter. A study by Whittenberger and Nutting (5) on the sloughing of potatoes indicated that in waxy and soggy tissues the cells showed less rounding and tended to remain firmly stuck together.

The present study was conducted to investigate the relationship between mealiness and certain microscopic observations of the raw and cooked product of five potato varieties grown at four different locations.

MATERIALS AND METHODS

In co-operation with the Experimental Farm, Brandon, Manitoba, and the University of Manitoba, Winnipeg, Manitoba, samples of the varieties Canso, Irish Cobbler, Manota, Netted Gem, and Warba potatoes were obtained. These were grown from tubers of common variety lots at the following locations in 1953: (1) Brandon (heavy valley soil); (2) Brandon (light sandy soil); (3) Winnipeg (heavy clay soil), and (4) Morden (silty clay loam). Testing of the potatoes was conducted in November and December of 1953. The specific gravity of a 10-lb. lot of each sample was determined by means of a Bewell hydrometer. The mean readings thus obtained were later correlated with the texture ratings for the cooked tubers.

Duplicate cooking tests, with three medium-sized tubers typical of the sample in each, were performed on each variety from each location. The three tubers in each test were peeled, boiled, and riced, and the texture rated subjectively for mealiness (maximum = 4) by a panel of four persons. The following scale was adopted as a guide for the subjective rating:

Rating	Numerical value	Description
4	4.0	Very dry, fluffy, free from waxiness.
4 −	3.7	Very mealy, not completely dry but substantially free from waxiness.
3 +	3.3	Mealy, may have slight sogginess or waxiness.
3	3.0	Slightly mealy, mealiness evident but not pronounced.
3 −	2.7	Medium soggy, lacks mealiness but not definitely soggy, may have some waxiness.
2 +	2.3	Soggy, somewhat undesirable because of sogginess.
2	2.0	Very soggy, wet or soapy, undesirable.

The numerical rating values of the four judges were averaged for each potato sample.

Microscopic examinations were made of three typical tubers of each variety from each location. Each tuber was peeled and halved and, from a freshly cut internal section of the raw tissue, a minute quantity was scraped and transferred to a glass slide. The scraped tissue was obtained from an area midway between the outside and the centre of the cut tuber, the same area from which cooked cells were taken later. A drop of water plus a drop of iodine stain were added and a cover slip applied. The diameters of 40 starch granules, selected at random from each tuber, were measured at 360 $\times$ magnification, and the mean granule diameter calculated. Half of each tuber was cooked for 25 minutes in boiling water. This half-piece in turn was cut in half in the opposite direction. A minute quantity of tissue from the freshly cut section, taken midway between the centre of the tuber and the outside, was dispersed gently in a drop of water on a glass slide and stained with iodine. No cover slip was applied in order to avoid distortion of the cells.

The microscopic examinations of the cooked potato cells included observations of cell condition, fragmentation, and wall thickness. "Cell condition" referred to the ability of the cells to remain intact with smooth margins rather than become distorted and ragged. "Fragmentation", which was often associated with condition, referred to the amount of extraneous starch material released from ruptured cells. "Wall thickness" referred to the relative thickness of the transparent wall surrounding each cell.

Numerical ratings were accorded to the observations on each sample according to the following scale:

Condition	Fragmentation	Wall thickness	Numerical rating
Even	None	Very thick	6
Very slightly ragged	Very slight	Thick	5
Slightly ragged	Slight	Medium thick	4
Medium ragged	Medium	Medium	3
Very ragged	Heavy	Thin	2
Mushed	Very heavy	Very thin	1

Analyses of variance were conducted on the resulting data. Correlation coefficients were calculated for the relationships between texture ratings and the other observed factors.

RESULTS AND DISCUSSION

Highly significant variations between varieties occurred for all factors (Table 1). Highly significant variations occurred also between locations for texture rating and for cell wall thickness but not for cell condition and

TABLE 1.—MEAN SQUARE VALUES FOR TEXTURE RATING, STARCH GRANULE SIZE AND COOKED CELL CHARACTERISTICS

Variation due to	D.F.	Texture rating	Raw granule diam.	Cell condition	Cell fragmentation	Cell wall thickness
Varieties	4	1.389**	368.0**	3.099**	8.729**	3.715**
Location	3	0.345**	65.5	0.577	1.082	2.833**
Var. × Loc.	12	0.177**	27.9	0.836	0.624	1.113
Error	40	0.037	30.8	0.463	1.392	0.617

** Significant to the 1 per cent level.

TABLE 2.—VALUES FOR VARIETY MEANS, F AND LEAST SIGNIFICANT DIFFERENCES

Variety	Texture rating	Raw granule diam. (microns)	Condition	Fragmentation	Wall thickness
Canso	2.97	41.9	4.15	4.82	3.75
Netted Gem	2.82	46.9	4.55	5.32	4.05
Manota	2.62	34.4	3.60	3.70	4.10
Irish Cobbler	2.34	34.6	3.62	3.95	4.25
Warba	1.92	35.6	3.50	3.25	5.20
F	37.5**	11.9**	6.69**	6.27**	6.02**
L.S.D.	0.19	4.5	0.56	0.96	0.78

** Significant to the 1 per cent level.

TABLE 3.—RELATIONSHIP OF TEXTURE RATING WITH SPECIFIC GRAVITY, STARCH GRANULE DIAMETER, AND COOKED CELL CHARACTERISTICS

Correlation between	r
Texture and specific gravity	0.706**
Texture and raw granule diameter	0.473*
Texture and cell condition	0.445*
Texture and cell fragmentation	0.650**
Texture and cell wall thickness	−0.704**

* Significant to the 5 per cent level.
** Significant to the 1 per cent level.

cell fragmentation. The interaction of varieties and locations produced a highly significant variation in texture rating. From data not reported in detail here, it was evident that the texture ratings of the varieties grown at Winnipeg were higher than those from the other three locations and the cell wall thickness was greatest for the two Brandon locations.

Variety mean values (Table 2) showed that texture ratings for Canso and Netted Gem were significantly highest (all locations considered) and that Warba was lowest. The diameter of the raw granules was also significantly highest for Canso and Netted Gem. The same two varieties maintained the most even cell margins and showed least fragmentation. Warba exhibited the thickest cell wall and had the lowest ratings for texture, cell condition, and cell fragmentation.

Coefficients of correlation (Table 3) indicated that relationships of texture ratings with values for specific gravity, cell fragmentation and cell wall thickness were highly significant. The relationship between texture and wall thickness was inverse. Texture ratings also showed a significant positive association with raw granule diameter and with cooked cell condition.

The above data, though limited to one season, showed that substantial differences in the size of the potato starch granules and the nature of the cooked potato cells occurred between different varieties and between different locations. No attempt was made to determine how much of the variation was due to genetic and how much was due to environmental effects.

REFERENCES

1. Briant, A. M. Physical properties of starch from potatoes of different culinary quality. Food Res. 10: 437-444. 1945.
2. Freeman, M. E., and W. S. Ritchie. Pectins and the texture of cooked potatoes. Food Res. 5: 167-175. 1940.
3. Nylund, R. E., and A. J. Poivan. The influence of variety and date of planting on the relative cooking quality of potatoes graded according to specific gravity. Am. Potato J. 30: 107-118. 1953.
4. Reeve, R. M. Histological survey of conditions influencing texture in potatoes. 1. Effects of heat treatments on structure. Food Res. 19: 323-332. 1954.
5. Whittenberger, R. T., and G. C. Nutting. Observations on the sloughing of potatoes. Food Res. 15: 331-339. 1950.

THE CONCENTRATE TO ROUGHAGE RATIO IN THE RATION AS IT AFFECTS THE PERFORMANCE TESTING OF RAMS[1]

F. WHITING AND R. D. CLARK

Canada Department of Agriculture, Lethbridge, Alberta

[Received for publication July 8, 1955]

ABSTRACT

An experiment to evaluate rations for performance or progeny testing was carried out during 1952-53 and 1953-54 with 19 sire groups of four ram lambs, each fed rations with four different concentrate to roughage ratios during various body weight and time intervals. The criteria for suitability of a ration were high variability of gain and feed efficiency within a ration-lot and a high correlation between daily gain and feed efficiency. One ram lamb from each sire group was assigned to each of four lots. The concentrate to roughage ratios studied were 2 : 1, 1 : 1, 1 : 2, and free choice of concentrate and roughage (approximately 5 : 1). The rams in the three lots fed constant ratios of concentrate to roughage were fed predetermined amounts of feed, based upon body weight. All rams were fed individually. The data were analysed for the body weight ranges of 90 to 130 lb., 110 to 150 lb., and 90 to 150 lb., and during the first 112 days on experiment, and the total time on experiment (162 days first year and 210 days second year).

There were highly significant differences between lots in average daily gains and feed efficiency, but there were no essential differences in variability within those lots fed rations with concentrate to roughage ratios of 2 : 1, 1 : 1, and 1 : 2. The lot fed concentrate and roughage free choice was more variable in daily gains but not in feed efficiency than the other lots. Of the five weight and time intervals studied the time interval involving the first 112 days on experiment was the most variable.

Sire group differences in daily gains were significant only during the body weight range of 90 to 130 lb., and in feed efficiency during the first 112 days on feed.

There were higher correlations between daily gains and feed efficiency for the three lots fed constant ratios of concentrate to roughage than for the lot fed free choice. There were no significant differences between the correlations within the various weight ranges and time intervals studied.

Daily gain and initial weight accounted for approximately 70 per cent of the variability in feed efficiency.

The average correlation between initial weight and gain was non-significant, but significant between initial weight and feed efficiency.

INTRODUCTION

Less emphasis and interest have been shown in performance and progeny testing of sheep than for other classes of farm animals. Also, less is known regarding the heritabilities of certain economically important characteristics of sheep, such as gaining ability and feed efficiency, than is known for cattle.

Sheep production in the range areas of western Canada is based upon the production of feeder lambs by the rancher and the fattening of these lambs, mainly by farmers, in irrigated areas adjoining the range areas. If, as has been found for cattle, the rate of gain of lambs on feed is a highly heritable characteristic, it is of economic importance to consider this in a breeding program.

Shelton *et al.* (9) have reported the results of four years of work in progeny and performance testing of 576 rams. Their data indicate that

[1] Contribution from the Division of Animal Husbandry, Experimental Farms Service.

highly heritable differences exist between the performance of offspring from different sires. Their heritability estimate for daily gains was 0.58. They found that there was a highly significant positive correlation between initial weight and average daily gains. Feeds per 100 lb. gain was highly correlated with initial weight (positive) and average daily gain (negative). By the method of multiple correlation more than 90 per cent of the variation in feed efficiency could be accounted for by a knowledge of initial weight, rate of gain, and other related variables. They concluded that little or no value had been realized from the data collected on feed efficiency.

Knapp and co-workers (2 and 4) found that steers were much less variable in daily gains on a limited than on an unlimited feed intake. Variance analyses showed that on limited feeding sire groups were significantly more alike than would be expected by chance, whereas on unlimited feeding the sire groups were significantly different from each other. They concluded that forced, or ad libitum feeding is the best method by which differences in ability to grow may be determined. Williams and Wood (11), in discussing performance testing of beef cattle, felt that the feed intake should be based on the most acceptable feeding standard available and should be at a daily level predetermined on the basis of the animal's weight at the time. On unlimited feeding, selection is based, at least in part, on appetite, whereas on limited feed intake the efficiency of feed utilization is emphasized. Which method is the better depends to some extent upon aims of the breeding program.

It was felt that before a program of performance and progeny testing of sheep was initiated a study should be made of the effects of rations upon the gaining performance and feed efficiency of young rams. However, since facilities were not available at Lethbridge for testing the suitability of rations or methods of feeding by actual progeny testing, the criteria used for determining the most suitable ration or method of feeding were: (1) variability of animals within a ration lot, and (2) correlations between rate and efficiency of gain. In addition, the variations within lots and within sire groups during various body-weight ranges and time-constant periods were studied.

PROCEDURE

In each of two years (1952-53 and 1953-54), 12 sire groups of four ram lambs each were used. These rams represented Rambouillet, Canadian Corriedale, and Romnelet breeding. One ram lamb from each sire group was placed in each of four lots. The same kinds of concentrate and roughage were fed to the four lots, the rations differing only in the proportions of concentrate to roughage. These were as follows: *Lot 1*—2 : 1, *Lot 2*—1 : 1, *Lot 3*—1 : 2, and *Lot 4*—free choice.

The roughage was composed of $\frac{2}{3}$ alfalfa and $\frac{1}{3}$ crested wheat grass hay and was chopped to facilitate weighing and feeding. The concentrate was composed of (in pounds): barley 500; oats 240; dried molasses beet pulp 150; linseed oilmeal 100; bonemeal 5; and salt (cobaltized) 5. All rams were fed individually twice daily.

TABLE 1.—DAILY FEED ALLOWANCE (LB. AIR-DRY WEIGHT) ACCORDING TO BODY WEIGHT

Body weight (lb.)	Lot 1	Lot 2	Lot 3
	(2 : 1)[1]	(1 : 1)	(1 : 2)
60	2.55	2.60	2.85
70	2.70	2.80	3.00
80	3.00	3.00	3.30
90	3.15	3.20	3.45
100	3.30	3.40	3.60
110	3.45	3.60	3.75
120	3.60	3.70	3.90
130	3.75	3.80	4.05
140	3.90	4.00	4.20
150	4.05	4.20	4.35
160	4.20	4.40	4.50
170	4.35	4.60	4.80

[1] Ratio of concentrate to roughage.

Table 1 shows the daily amounts of feed fed to each ram in Lots 1, 2, and 3 according to body weight. The rams in Lot 4 had free choice of roughage and concentrate during two 2-hour periods each day.

All rams were weighed individually at 2-week intervals during the first year and at weekly intervals during the second year of this experiment. The daily feed allowance for Lots 1, 2, and 3 was adjusted after each weighing.

The rams were on feed each year for a period 2 to 3 weeks before the experiment was started. They were on experiment for a total of 162 days during the first year and 210 days the second year.

No death losses occurred during the first year but four rams died or were destroyed during the second year. None of these deaths was attributed to the ration fed. (Two deaths were caused by urinary calculi; one ram injured himself and was destroyed; and one developed an inflamed testicle and was destroyed.) One ram during the first year refused to consume its daily allowance of feed. The sire group from which the ram refused to consume its feed, and the four sire groups from which rams died or were destroyed, were removed from the experiment and their data are not considered in this paper.

The rams varied in initial weight from 63 to 108 lb. in 1952-53 and from 58 to 91 lb. in 1953-54; and in final weights from 134 to 210 lb. in 1952-53 and from 134 to 229 lb. in 1953-54.

RESULTS AND DISCUSSION

An analysis of variance indicated that there were no significant differences between the two years in daily gains or feed efficiency so the data within each lot for the two years were combined for all analyses.

Variability Within Lots and Within Sire Groups

Table 2 shows a summary of the data in terms of average daily gain, feed efficiencies (TDN/100 lb. gain) and variability of gains and feed efficiencies during various weight ranges and time intervals. TDN values were determined from digestion trials with the rams on experiment, using chromic oxide (Cr_2O_3) as an indicator.

TABLE 2.—THE INFLUENCE OF CONCENTRATE TO ROUGHAGE RATIO UPON THE AVERAGE DAILY GAIN, FEED EFFICIENCY, AND VARIABILITY OF DAILY GAIN AND FEED EFFICIENCY DURING VARIOUS WEIGHT AND TIME INTERVALS

	Lot 1	Lot 2	Lot 3	Lot 4	All lots[1]
	(2 : 1)	(1 : 1)	(1 : 2)	(Free choice)	—
Av. initial wt. (lb.)	81	84	82	82	82
Av. final wt. (lb.)	162	157	147	185	163
Av. days on experiment	186	186	186	186	186
	Average daily gain (lb.) and coefficient of variability (C.V.)				
90 to 130 lb. body weight					
Daily gains	0.46	0.40	0.34	0.57	0.44
C.V.	9.5	14.4	8.4	22.7	15.5[1]
110 to 150 lb. body weight					
Daily gains	0.48	0.41	0.38	0.60	0.46
C.V.	10.5	11.2	8.8	17.7	14.2
90 to 150 lb. body weight					
Daily gains	0.46	0.40	0.36	0.58	0.45
C.V.	7.6	10.7	7.8	18.2	13.1
First 112 days on experiment					
Daily gains	0.43	0.38	0.33	0.55	0.42
C.V.	12.5 (12.0)[2]	14.1 (13.3)	11.0 (11.3)	19.4 (16.6)	14.0 (14.0)
Total period on experiment (186 days)					
Daily gains	0.44	0.39	0.35	0.57	0.44
C.V.	8.1 (8.1)[2]	9.0 (9.0)	7.0 (7.0)	14.5 (13.4)	11.1 (10.9)
	Feed efficiency (TDN/100 lb. gain) and C.V.				
90 to 130 lb. body weight					
Feed efficiency	494	563	625	503	546
C.V.	9.5	14.4	9.6	16.1	10.8[1]
110 to 150 lb. body weight					
Feed efficiency	527	580	624	539	568
C.V.	10.6	11.2	8.5	12.6	11.1
90 to 150 lb. body weight					
Feed efficiency	520	572	625	525	561
C.V.	8.5	12.1	7.5	11.2	9.6
First 112 days on feed					
Feed efficiency	507	572	641	531	563
C.V.	11.8 (11.8)[2]	13.8 (14.2)	11.4 (11.4)	9.6 (9.8)	11.0 (10.7)
Total period on experiment (186 days)					
Feed efficiency	530	569	614	567	570
C.V.	10.0 (9.4)[2]	8.8 (9.1)	7.5 (7.2)	5.8 (5.3)	7.7 (7.0)

[1] Variability between lots and sire groups removed.
[2] Numbers in parentheses are C.V.'s when corrections have been made by analyses of covariance for differences in initial weights.

There were significant differences ($P < 0.01$) in gains and feed efficiencies between lots. However, there were no essential differences in variability of gains and feed efficiencies between Lots 1, 2, and 3. Lot 4 was more variable in daily gains than the other three lots, but not so in feed efficiencies. There was little difference in the variability within lots between the various time or weight-range intervals that were considered in this study.

Since the variability in daily gains and feed efficiency within Lots 1, 2, and 3 was essentially the same, it would indicate that the concentrate to roughage ratio within the limits of 2 : 1 to 1 : 2, when a restricted feed intake is used, is not important in deciding upon a ration for performance or progeny testing. However, if, as has been indicated by Knapp and Baker (2), a ration or system of feeding that gives a high variability between animals is desirable in performance testing, the data indicate that ad libitum feeding is more desirable than controlled feeding.

It is not possible to determine from the data in this experiment whether a free-choice system of feeding is more desirable in performance and progeny testing than the ad libitum feeding of a constant ration (i.e., constant ratio of concentrate to roughage). However, since a given amount of TDN from a roughage does not result necessarily in the same amount of energy being available to the animal body as from the same amount of TDN from a concentrate (8), it is not possible to compare accurately the feed efficiencies of animals fed different concentrate to roughage ratios. Therefore, it would appear that a more accurate estimate of feed efficiency can be obtained by feeding a ration of constant ratio of concentrate to roughage.

In this study there were no essential differences in the within-sire group variability for gains and feed efficiency between the various weight-range and time intervals studied. However, the longer feeding periods (90 to 150 lb. body weight range and the total feeding period) were somewhat less variable than the shorter periods. Although in all periods considered in this experiment there were highly significant differences between lots, only during the body weight range of 90 to 130 lb. were differences in daily gain between sire groups significant. In the case of feed efficiency there were highly significant ($P < 0.01$) sire differences during the weight interval of 90 to 130 lb. and significant differences ($P < 0.05$) during the first 112 days and total feeding periods, when the feed efficiencies were adjusted for differences in initial weight.

These data indicate that differences in gain or feed efficiencies between rams and/or sire groups are more apparent during the early phases of the feeding period (90 to 130 lb. body weight or the first 112 days on feed) than after the animals have been on feed for some time. Knapp and Woodward (5) reported that the heritability of live weight in cattle increased rapidly from the second to sixth 28-day period on feed after weaning and thereafter there was little change. They suggest that a feeding period as short as 112 days can be used to indicate genetic growth ability where ad libitum feeding is practised.

Correlations Between Gain and Feed Efficiency

Table 3 shows the correlations within each lot for gains and feed efficiency during the various body weight range and time intervals studied.

TABLE 3.—CORRELATIONS BETWEEN DAILY GAIN AND FEED EFFICIENCY AS INFLUENCED BY CONCENTRATE TO ROUGHAGE RATIO AND DURING VARIOUS WEIGHT AND TIME INTERVALS

	Lot 1	Lot 2	Lot 3	Lot 4	All lots[2]
Concentrate to roughage ratio	2 : 1	1 : 1	1 : 2	Free choice	—
90 to 130 lb. body weight	0.97[1]	0.97	0.82	0.80	0.69
110 to 150 lb. body weight	0.98	0.93	0.98	0.87	0.63
90 to 150 lb. body weight	0.95	0.97	0.96	0.83	0.72
First 112 days on experiment	0.74	0.90	0.90	0.75	0.76
First 112 days on experiment adjusted for initial weight	0.90	0.98	0.98	0.89	0.80
Total period (186 days)	0.72	0.84	0.81	0.31	0.68
Total period adjusted for initial weight	0.83	0.92	0.89	0.65	0.80

[1] All the correlations are negative and all highly significant ($P < 0.01$) except the value 0.31.
[2] Average correlations (10).

It will be observed that the correlations are all negative and are greater for the rams fed according to body weight than for those fed free choice. This may be due, as mentioned previously, to the inadequacy of TDN as a measure in converting roughages and concentrates to a common value.

There were no differences in the correlation coefficients between the various weight-range and time intervals when the time intervals were corrected by analyses of covariance for differences in initial weights. The low correlation between daily gain and feed efficiency for Lot 4 during the total period on experiment was due probably to the effect of differences in initial weight of the rams in that the correlation became −0.65 when feed efficiencies were adjusted for differences in initial weights. Highly significant correlations between rate of gain and feed efficiency for cattle during weight-constant periods or during time-constant periods when adjusted for differences in body weight have been reported (1, 3, and 7). When not so adjusted the correlations were mostly non-significant.

The multiple correlation coefficient (R) for feed efficiency, initial weight, and gain was 0.814 during the first 112 days on experiment and 0.837 during the total feeding period. Thus gain and initial weight accounted for approximately 70 per cent (R^2) of the total variability in feed efficiency during these periods. This finding is in general agreement with the results reported by Shelton *et al.* (9).

The within-lot correlation between initial weight and gain was + 0.101 for the entire feeding period and + 0.110 for the first 112 days on feed indicating that initial weight did not influence the daily gains within the limits of this experiment. Shelton *et al.* (9) reported a highly significant positive correlation between initial weight and gain of rams. The low correlation between initial weight and gain in the present experiment may have been due, in part, to the fact that the feed intake was controlled in three of the four lots each year. However, when Lot 4, that was fed free-choice, was considered alone, the correlation between initial weight and gain was essentially the same ($r = 0.08$). Lush (6), working with cattle

and swine, found that the correlation between initial weight and gain was 0.24 for steers and 0.52 for market pigs. However, Knapp *et al.* (4) reported a correlation coefficient of −0.088 between weaning weight and gain of steers in the feedlot when animals in the same year were considered.

The average correlation (lot and sire variation removed) between initial weight and feed efficiency was 0.41 ($P < 0.01$) during the entire feeding period and 0.30 ($P < 0.05$) during the first 112 days on feed. This is further illustrated in that the average feed required (TDN) per 100 lb. gain between the body weight ranges of 70-90, 90-110, 110-130, 130-150, and 150-170 lb. were 488, 530, 555, 593, and 620 lb. respectively. The partial correlation coefficient between initial weight and feed efficiency (daily gains held constant) was 0.91** during the total feeding period and 0.80** during the first 112 days on feed.

It is evident from the correlation coefficient and the other data presented that differences in feed efficiency between animals should be compared, if possible, at the same body weights. If this is not possible the feed efficiency data should be adjusted for differences in body weight. Knapp and Baker (3) have pointed out that selection on gross efficiency in time-constant feeding periods is generally misleading and often erroneous. Since gain is not influenced to as marked an extent by initial weight as is feed efficiency, selection in a time-constant feeding period should be based upon gains and not upon feed efficiency.

REFERENCES

1. Grizzle, J. E., and C. W. Kincaid. The relationship between body weight, daily gain, and efficiency of feed utilization in beef cattle. J. Anim. Sci. 13 : 958. (*Abstract*). 1954.
2. Knapp, Bradford Jr., and A. L. Baker. Limited vs. full feeding in record of performance tests for beef cattle. J. Anim. Sci. 2 : 321-327. 1943.
3. Knapp, Bradford Jr., and A. L. Baker. Correlation between rate and efficiency of gains in steers. J. Anim. Sci. 3 : 219-223. 1944.
4. Knapp, Bradford, Jr., A. L. Baker, J. R. Quesenberry, and R. T. Clark. Record of performance in Hereford cattle. Montana Agr. Expt. Sta. Bull. 397. 1941.
5. Knapp, Bradford, Jr., and R. R. Woodward. Heritability of weights of beef steers by months during the feeding period. J. Anim. Sci. 10 : 1026-1027. (*Abstract*). 1951.
6. Lush, Jay L. Predicting gains in feeder cattle and pigs. J. Agr. Res. 42 : 853-881. 1931.
7. MacDonald, M. A., and Ralph Bogart. Relationship between rate and efficiency of gain and type in breeding beef cattle. New Zealand Sci. Tech. J. 36 : 460-469. 1955.
8. Moore, L. A., H. M. Irvin, and J. C. Shaw. Relationship between TDN and energy values of feeds. J. Dairy Sci. 36 : 93-97. 1953.
9. Shelton, Maurice, J. C. Miller, W. T. Magee, and W. T. Hardy. J. Anim. Sci. 13 : 215-228. 1954.
10. Snedecor, George W. Statistical methods. 4th ed. The Iowa State College Press, Ames, Iowa. 1946.
11. Williams, C. M., and A. J. Wood. Beef bull research project. Dept. Extension, Univ. British Columbia. 1952. (*Mimeographed*).

THE EFFECTS OF MOULD GROWTH ON THE DIGESTIBILITY AND FEEDING VALUE OF GRAINS FOR SWINE AND SHEEP[1]

A. R. JONES[2], L. M. BEZEAU[3], B. D. OWEN[4] AND F. WHITING[5]

Canada Department of Agriculture, Beaverlodge and Lethbridge, Alberta

[Received for publication June 15, 1955]

ABSTRACT

Experiments were carried out with growing-fattening swine and lambs to compare the digestibility and relative feeding value of mouldy and non-mouldy oats and wheat. The digestibility of mouldy oats, both with swine and lambs, was reduced significantly ($P < 0.05$) as compared to non-mouldy oats. However, mouldy wheat was more highly digestible by swine than non-mouldy wheat. When mouldy oats constituted 25 per cent of the growing and 36 per cent of the fattening ration there were no differences in growth rate and feed efficiency of swine compared to those fed the same quantity of non-mouldy oats; nor were there any differences in daily gains or feed efficiency between swine fed mouldy or non-mouldy wheat. Lambs fed a grain ration in which mouldy oats constituted 50, 75, or 100 per cent made slower and less efficient gains than lambs fed a grain ration of non-mouldy oats or a ration of 25 per cent mouldy oats. In these experiments mouldy grains were not unpalatable to swine and sheep.

INTRODUCTION

The frequent occurrence of unfavourable harvesting and storing conditions for grain in western Canada often results in considerable quantities of mould-damaged grains. Since these grains are of limited value for milling and processing, they are used largely as feed for live stock and poultry.

The question of harmful effects and lowered palatability is often raised when mouldy grains are being considered as a feed. A review of the literature by Ewing (1) and Morrison (2) indicates that, although some death losses have occurred that were attributable to the feeding of mouldy grain, most moulds are harmless to live stock and poultry. Very little information is available on the relative palatability, digestibility, and feeding value of mouldy and non-mouldy grains.

Experiments were undertaken to determine the digestibility and feeding value of mouldy and non-mouldy wheat and oats for growing and fattening swine and lambs. The feeding trials and digestibility trials were conducted, respectively, at the Experimental Farms at Beaverlodge and Lethbridge, Alberta.

PART I. SWINE EXPERIMENTS

PROCEDURE

Mouldy oats and wheat, which had remained in the swath or stook over winter and had been harvested in the spring, were obtained for these

[1] Contribution from Division of Animal Husbandry, Experimental Farms Service, Canada Department of Agriculture, Ottawa.

[2] Formerly Animal Husbandman, Experimental Farm, Beaverlodge, Alta.
[3] Chemist (Animal Nutrition), Experimental Farm, Lethbridge, Alta.
[4] Animal Husbandman, Experimental Farm, Beaverlodge, Alta.
[5] Animal Nutritionist, Experimental Farm, Lethbridge, Alta.

experiments from the 1951 crop in the Peace River area of Alberta. Normal grains harvested in the fall of 1951 were used for comparison with the mouldy grain. A description and the chemical composition of the grains used in the experiment are shown in Table 1. The fungi found on the mouldy wheat and oats used in the experiments included *Aspergillus* spp., *Penicillium* spp., *Rhizopus nigricans*, *Actinomyces* sp., *Alternaria*, *Cladosporium*, *Mesobotrys* and *Trichoderma*[1]. It should be noted that many of these moulds are found on most grains.

TABLE 1.—DESCRIPTION AND CHEMICAL COMPOSITION OF THE MOULDY AND NON-MOULDY GRAINS USED IN THIS STUDY

	Oats			Wheat	
	Non-mouldy	Mouldy	Mouldy	Non-mouldy	Mouldy
Official grade	No. 1 Feed	Rejected	Sample	No. 5	Feed
Weight per bushel (lb.)	36	30	28	56	52
Moisture (%)	8.4	8.2	8.1	10.2	10.1
Protein (N × 6.25) (%)	11.9	10.1	9.6	12.9	13.8
Ether extract (%)	5.8	5.3	5.7	2.2	2.4
Crude fibre (%)	12.7	16.3	18.0	3.2	2.7
Ash (%)	3.9	4.9	5.8	1.9	1.7
Energy (cal./gm.)	4.37	4.38	4.34	4.15	4.16

Digestibility Trail

Rations were formulated from each of the 5 grains shown in Table 1. To each 95 lb. of grain were added 3 lb. of dried skimmilk, 1.6 lb. of minerals and vitamins similar to those used in a previous study (3), and 0.4 lb. of an antibiotic feed supplement[2]. Four weanling barrows were used. They were allotted to their rations by use of a 4 × 5 incomplete Latin square design. Each collection period was of 10 days' duration preceded by a 10-day preliminary period. Ferric oxide was used as a marker. Methods of feeding, collection of feces and urine, and chemical analyses were the same as previously described (3).

Feeding Studies

Six rations were compounded from the 5 lots of grain. A basal ration of 25 per cent No. 1 Feed oats, 62.5 per cent No. 5 wheat and 12.5 per cent of a supplement containing animal and vegetable protein, minerals, and an

[1] The authors wish to acknowledge the assistance of W. P. Campbell, Plant Pathology Laboratory, Edmonton, Alta., in identifying the fungi present on the grains used in this study.

[2] The antibiotic supplement (Aurofac 2A) was generously supplied by R. F. Elliott, Lederle Laboratories, Pearl River, N.Y.

TABLE 2.—THE DIGESTIBILITY OF MOULDY AND NON-MOULDY GRAIN BY SWINE

	No. 1 Feed oats (non-mouldy)	Rejected oats (mouldy)	Sample oats (mouldy)	No. 5 wheat (non-mouldy)	Feed wheat (mouldy)	L.S.D.*. (P = 0.01)
Av. weight of pigs (lb.)	64	66	58	71	58	—
Av. daily feed consumed (lb.)	3.2	3.3	2.9	3.1	2.8	—
Av. digestibility coefficients (%)						
Dry matter	65.5	59.4	53.7	83.7	86.8	2.2
Organic matter	67.1	61.0	55.0	85.3	88.5	2.2
Protein (apparent)	83.6	81.0	79.4	81.0	86.2	1.2
Ether extract	87.2	88.6	87.0	60.0	67.0	12.9
Crude fibre	26.2	12.5	35.4	30.0	18.9	14.7
Nitrogen-free extract	72.8	67.6	62.4	90.8	92.5	2.8
Gross energy	66.0	59.4	54.2	82.1	85.9	2.5
Total digestible nutrients (TDN)	65.3	59.0	53.5	76.4	79.4	—
Digestible calories (therms/100 lb.)	122.6	112.3	102.6	142.9	153.1	—

*Least significant difference.

TABLE 3.—AVERAGE FEED CONSUMPTION, DAILY GAINS, AND EFFICIENCY OF GAINS AS INFLUENCED BY THE USE OF MOULDY GRAINS IN THE RATION

Lot No.	1	2	3	4	5	6
Grain in ration	No. 1 Feed oats, No. 5 wheat	Sample oats, No. 5 wheat	Rejected oats, No. 5 wheat	No. 1 Feed oats, feed wheat	Sample oats feed wheat	Rejected oats, feed wheat
Number of pigs per lot	9	9	9	9	9	9
Av. number of days on feed	125	131	127	125	131	131
Av. daily feed consumed (lb.)						
40 to 110 lb. body weight	3.40	3.26	3.33	3.39	3.16	3.27
110 to 200 lb. body weight	5.90	5.77	5.66	5.67	5.31*	5.61
40 to 200 lb. body weight	4.64	4.49	4.50	4.48	4.19	4.42
Av. daily gain (lb.)						
40 to 110 lb. body weight	1.12	1.05	1.11	1.08	1.05	1.06
110 to 200 lb. body weight	1.47	1.42	1.44	1.51	1.43	1.42
40 to 200 lb. body weight	1.29	1.23	1.27	1.28	1.23	1.23
Feed per 100 lb. gain (lb.)						
40 to 110 lb. body weight	308	311	302	317	303	310
110 to 200 lb. body weight	404	410	396	378	376	397
40 to 200 lb. body weight	362	368	357	361	344	359

* Significant ($P < 0.05$). L.S.D. = 0.29 lb.

aureomycin feed supplement (Aurofac A) was fed to Lot 1 pigs from weaning (40 lb.) to 110 lb. body weight[1]. The proportions of oats, wheat, and supplement were changed to 36, 58 and 6 per cent respectively during the period from 110 to 200 lb. body weight. The No. 1 Feed oats were replaced by Sample oats in Lot 2 and by Rejected oats in Lot 3. The No. 5 wheat was replaced by the Feed wheat in Lots 4, 5 and 6 with the oat portions of the latter rations duplicating those in Lots 1, 2 and 3, respectively. Nine pigs, one from each of nine litters, were allotted at random to each of the 6 lots when they reached a body weight of 40 lb. The pigs were individually hand fed according to appetite. All pigs were weighed at 2-week intervals and oftener as they approached 200 lb. They were marketed as closely as possible to the date on which they reached 200 lb. live weight.

RESULTS AND DISCUSSION

Digestibility Trial

The average values from the four pigs on each grain are shown in Table 2. In calculating these values it was assumed that the organic matter and protein of skimmilk were 98 per cent digestible and that the dry matter of the mineral mix was 50 per cent digestible by the pig. The organic matter, protein, N.F.E. (nitrogen-free extract), and gross energy of No. 1 Feed oats were digested to a greater extent ($P < 0.01$) than the same entities of the Rejected oats and these in turn were more digestible than those in the Sample oats. However, the organic matter, protein, and gross energy of the Feed wheat (mouldy) were more highly digestible than the same constituents of the No. 5 wheat.

Feeding Studies

Data for average feed consumption, rate of grain, and efficiency of feed utilization are shown in Table 3. There were no significant differences ($P < 0.05$) between lots in average daily gains, feed efficiency or average daily feed consumption, with the exception that the pigs in Lot 5, fed mouldy oats and wheat, consumed less feed ($P < 0.05$) during the period 110-200 lb. body weight than the other lots.

The differences between lots in the feeding study were not so great as might have been expected considering the differences obtained during the digestibility trials. However, since the mouldy oats made up only 25 per cent of the growing ration and 36 per cent of the finishing ration it is probable that differences in feeding value, if such differences existed, were masked by the other ingredients in the ration.

Considering the higher fibre content and the lowered digestibility of the mouldy oats as compared to the No. 1 Feed oats, it is concluded that oats that have suffered mould damage to the extent of those used in these experiments are of lower feed value than non-mouldy oats, even though no significant differences were apparent when these grains were fed as part of the ration to growing-fattening pigs. In the case of wheat, there appeared to be no difference between the mouldy and non-mouldy lots used. However, in view of the higher protein and lower crude fibre content of the

[1] Feed grade fish oil was added to the ration daily during the growing period, to provide vitamins A and D.

mouldy wheat, as compared to the non-mouldy wheat, some question exists as to whether these two lots of wheat were of the same quality before mould growth took place in the one lot.

With the exception of the lowered feed intake by the pigs in Lot 5, mould damage did not significantly affect the palatability of the ration.

PART II. SHEEP EXPERIMENTS

Portions of the No. 1 Feed oats and the Rejected oats used in and described for the swine experiment were tested in the experiments with sheep.

Digestibility Trial

Five wether lambs, approximately 9 months of age, were used for the digestion study. Four rations were compounded as follows: (1) a mixed grass-alfalfa hay; (2) hay, 50 per cent, plus No. 1 Feed oats, 50 per cent; (3) hay, 50 per cent, plus Rejected oats, 50 per cent and (4) hay, 50 per cent, plus Rejected oats put through a fanning mill, 50 per cent. The rejected oats were put through the fanning mill for one ration to remove as many of the mould spores as possible, with the thought that this might increase the palatability of the oats. Each ration, plus one more ration not connected with this study, was fed to each of the five lambs. The lambs were allotted to the rations by use of a 5 $\times$ 5 Latin square design of experiment. One lamb proved to be very erratic in feed consumption and differed markedly and inconsistently in its digestion of the rations; hence all data pertaining to it were omitted from the study.

Each collection period was of 10 days' duration preceded by a 10-day preliminary period. Methods of analyses were the same as those used in Part I.

Feeding Studies

Forty-five feeder lambs were allotted on the basis of sex, weight, and type to five lots. Following a 10-day preliminary period, during which time the lambs were fed liberally a brome-alfalfa hay, they were placed on their respective rations. All lambs were offered 1.5 lb. per head daily of the brome-alfalfa hay. No. 1 Feed oats were fed to the lambs in Lot 1. The No. 1 Feed oats were replaced by Rejected oats to the extent of 25, 50, 75 and 100 per cent in Lots 2, 3, 4, and 5, respectively. During the first four weeks of the feeding period, linseed oilmeal was added to all rations at a level of 6 per cent of the grain portion or the ration.

Initially the lambs were offered 0.2 lb. of grain per head daily. This allowance was increased gradually to that amount which the lambs would clean up during two 30-minute periods daily. All lambs were fed individually and weighed at 14-day intervals.

RESULTS AND DISCUSSION

Digestion Trials

The average digestion coefficients obtained by difference for the No. 1 Feed oats, Rejected oats, and Rejected oats put through a fanning mill are shown in Table 4.

TABLE 4.—THE DIGESTIBILITY OF MOULDY AND NON-MOULDY OATS BY SHEEP

	No. 1 Feed oats (non-mouldy)	Rejected oats (mouldy)	Rejected oats (fanned) (mouldy)	L.S.D. (P = 0.01)
Av. daily ration consumed (lb.)	2.55	2.64	2.68	—
Av. digestibility coefficients (%)				
Dry matter	71.9	64.9	65.5	6.1
Organic matter	73.0	65.9	66.1	6.5
Protein	80.9	71.5	73.2	9.0
Ether extract	97.4	93.8	96.6	5.5
Crude fibre	37.7	42.0	43.5	12.8
Nitrogen-free extract	78.3	69.6	68.3	10.0
Gross energy	74.2	64.5	64.5	8.3
Total digestible nutrients	71.0	63.6	63.8	—
Digestible energy (therms/100 lb.)	147.1	128.0	128.0	—

The organic matter, protein, and energy content of the No. 1 Feed oats were more digestible ($P < 0.01$) than the same constituents of the Rejected oats. There were no significant differences in digestibility between the Rejected oats put through the fanning mill and those not put through. There were no apparent differences in palatability between the three lots of oats used.

Feeding Studies

The data for average feed consumption, rate of gain, and efficiency of feed utilization are shown in Table 5.

TABLE 5.—AVERAGE DAILY GAINS, FEED CONSUMPTION, AND EFFICIENCY OF GAINS AS INFLUENCED BY USE OF MOULDY OATS IN THE RATION OF FATTENING LAMBS

Lot No.	1	2	3	4	5
Rejected oats (%)	0	25	50	75	100
No. 1 Feed oats (%)	100	75	50	25	0
Number of lambs per lot	9	9	9	9	9
Av. initial weight (lb.)	67.3	67.2	67.6	68.2	67.4
Av. final weight (lb.)	105.6	106.8	102.2	105.3	105.6
Av. number of days on feed	94	97	99	97	101
Av. daily gain (lb.)*	0.42	0.41	0.35	0.38	0.38
Av. daily feed consumed (lb.)					
Hay	1.33	1.28	1.26	1.25	1.31
Grain	1.78	1.79	1.80	1.77	1.83
Feed per 100 lb. gain (lb.)					
Hay	334	322	338	333	348
Grain	441	442	483	473	486

*L.S.D. (P = 0.05) = 0.05 lb.

Average daily gains were somewhat lower in Lots 3, 4 and 5 but were significantly lower ($P < 0.05$) only in Lot 3. Lambs in Lots 3, 4 and 5 were less efficient in the utilization of their feed. This can be accounted for by the lowered digestibility of the Rejected oats as compared to the No. 1 Feed oats. There were no differences in average daily feed consumption between lots.

REFERENCES

1. Ewing, W. Ray. Poultry nutrition. 3rd ed., rev. W. Ray Ewing, Publisher, South Pasadena, Calif. 1947.
2. Morrison, Frank B. Feeds and feeding. 21st ed. Morrison Publishing Co., Ithaca, N.Y. 1948.
3. Whiting, F., and L. M. Bezeau. The nutritional value of frost-damaged and early-harvested cereal grains for swine. Can. J. Agr. Sci. 34 : 624-634. 1954.

NOTES ON LIFE-HISTORY AND HABITS OF THE SQUASH VINE BORER, *MELITTIA CUCURBITAE* (HARR.) (LEPIDOPTERA: AEGERIIDAE), IN SOUTHWESTERN ONTARIO[1]

L. A. MILLER[2]

Entomology Laboratory, Chatham, Ontario

[Received for publication April 14, 1955]

ABSTRACT

Adults of the squash vine borer, a serious pest of squashes and pumpkins in southwestern Ontario, begin to emerge during the last week of June and oviposit on the stems of susceptible cucurbit varieties. After an average incubation period of 9 days, the larvae hatch and bore into the stems of seedlings, causing wilting or death of the plants. There are four larval instars, development requiring an average total period of 29.7 days. Cocoons are formed at depths of 1 to 6 inches in the soil and pupation occurs the following spring and early summer.

In 1952 and 1953, emergence of a portion of the first generation was delayed and a partial second generation occurred.

INTRODUCTION

The squash vine borer, *Melittia cucurbitae* (Harr.), has been a recognized pest of squashes and pumpkins for over a century. In 1828 it was reported from Massachusetts (3), and it is known to have occurred in southwestern Ontario as early as 1871 (7). In Canada, its distribution appears to be limited to the Carolinean Zone, a very small area in southwestern Ontario (6). Hence, it has received little attention from Canadian investigators. Cucumbers, melons, and citrons rarely become infested in Ontario.

Friend (2), who studied the biology of the borer in Connecticut, included a concise literature review to 1931. The male and the female moths were described by Englehardt (1), who clarified the taxonomic status of the species. More recently, Hervey and Huckett (4) and Howe (5) reported on its biology in New York State.

The results reported herein were obtained from studies at Chatham, Ontario, in 1951, 1952, and 1953.

MATERIALS AND METHODS

Over 500 cocoons of the borer were obtained in September, 1951, by placing infested vines in a 9 × 6 by 6 ft. outdoor rearing cage with a wooden floor covered with 6 inches of soil. After the cocoons had been collected by sieving and washing the soil through a quarter-inch mesh screen, the floor was removed and the cocoons were buried 3 inches in the soil in the cage for overwintering. As the adults emerged into the cage the following summer, they were captured, paired, and placed in 16 × 9 by 9-inch plastic mesh-covered cages, with sliding glass fronts. Each cage contained one pair of moths and a potted seedling of Golden Hubbard squash. The

[1] Contribution No. 3302, Entomology Division, Science Service, Department of Agriculture, Ottawa, Canada.
[2] Assistant Entomologist.

seedlings were examined daily and when eggs were present the pots were removed to the insectary. Uninfested plants were then added to the cages and replaced as they became infested. This procedure continued until the females died. Eggs on the seedlings in the insectary were examined daily to determine the time of hatching.

First-instar larvae were dissected from the squash seedlings and placed individually in 1½-inch sections of stem. The sections were kept in screw-top glass vials containing moist paper towelling. The larvae were examined daily and the dates of moulting recorded. This method proved very satisfactory, although third- and fourth-instar larvae required frequent feedings. Larvae were also reared by placing them in holes drilled in 1-inch cubes of squash fruit. Individual stem or fruit sections containing 1 fourth-instar larva were placed in quart jars containing 4 inches of soil. At maturity, the larvae entered the soil and formed cocoons.

In the insectary, a minimum of 30 pairs of adults were observed. Data were obtained on the period of adult emergence, time of mating, period of oviposition, number of eggs per female, viability of eggs, incubation, number and duration of larval instars, and longevity of moths. Observations in the field were conducted on a quarter-acre of Golden Hubbard squash, one of the varities most susceptible to infestation by the borer.

LIFE-HISTORY AND HABITS

Adult

Although diurnal in habit, adults were seldom seen in the field. The flight of the adult and those of certain long-legged wasps are somewhat similar and care should be taken to distinguish between them in the field.

Adults began to emerge in the insectary on June 26 and 27 in 1952 and 1953, respectively, and had apparently completed emergence by mid-July in both years. In Ontario, a small portion of this generation may emerge as late as September: 8 adults emerged from August 16 to September 10, 1953, from cocoons collected in September, 1952, and held under field conditions. A partial second generation occurred in 1953: 2 adults emerged on September 13 and 20, from cocoons formed in August. Intact pupal exuviae were found in September of 1952 and 1953 in fields of squash not previously seeded to cucurbits; the adults from these pupae would almost certainly represent a partial second generation. The portion of the overwintering generation and the partial second generation that emerged in late August and September would be of little economic importance.

Mating was frequently observed on the same day that the pair emerged. Three days was the maximum pre-mating period for 36 pairs of adults. Males were not captured or observed in the squash field at any time during the investigations. Wild males were frequently captured, however, as they collected on the screen of the insectary where the females were caged.

The average pre-oviposition period of 33 females was 1.3 days, with a range of 1 to 4 days. The average oviposition period of 25 females was 3.3 days, with a range of 1 to 8 days.

The reddish-brown eggs are approximately 1 mm. long by 0.85 mm. wide and patterned with minute hexagonal reticulations. They are oval with a flat, somewhat depressed top and are usually indented slightly on

the circumference near the micropyle. The eggs were laid singly or in clusters. Eighty-nine per cent of 1,700 eggs were laid within 3 days of the beginning of oviposition; 90 per cent of the eggs were viable. Unmated females oviposited freely but the eggs were infertile. An average of 96 eggs per female was determined for the species and approximately 50 per cent of these were mature in newly emerged adults.

Confined females laid 53 per cent of their eggs on the upper leaf surfaces and only 15 per cent at the bases of the stems of the potted squash seedlings. Other oviposition sites were the lower leaf surface, the leaf petiole, the surface of the potting soil, the flower-pot, and the plastic mesh, the wood framework, and the glass front of the rearing cage. In the field, approximately 85 per cent of the eggs were laid at the base of the stem near the soil surface (Figure 1). They were also found on the leaves, petioles, epidermal hairs, and debris near the seedling. Frequently the eggs were on the stem below the soil surface. Although oviposition in the field was mainly completed by mid-July, sporadic egg laying occurred until mid-August.

Adults were comparatively short-lived in the insectary. Thirty-one females lived an average of 4.7 days, with a range of 2 to 10 days. Most died within 1 or 2 days after their last date of oviposition. Thirty-four males lived an average of 3 days, with a range of 1 to 8 days.

Larvae

There are four readily distinguishable larval instars in the species. These vary in length from 2 to 3 mm. in the newly emerged borer to 18 to 30 mm. in the mature borer.

After an average incubation period of 9 days, the larva hatches through a jagged hole on the rim of the egg. Newly hatched larvae were observed to spend approximately an hour wandering over the surface of the stem before entering it. The significance of this habit from a standpoint of control is apparent.

Table 1 shows that the durations of the larval instars approximate very closely those obtained by Howe (5), who found the average total duration of the instars to be 29.9 days in New York State.

TABLE 1.—DURATIONS OF LARVAL INSTARS OF THE SQUASH VINE BORER IN ONTARIO AS DETERMINED BY REARING INDIVIDUALS IN 1½-INCH STEM SECTIONS AND 1-INCH CUBES OF FRUIT OF GOLDEN HUBBARD SQUASH IN THE INSECTARY

Instar	Number observed	Duration, days	
		Average	Range
First	20	4.5	4- 7
Second	12	5.0	3-11
Third	5	5.2	4- 7
Fourth	10	15.0	5-20
Total	47	29.7	16-47

Wilting vines (Figure 2) toward the end of July usually indicate the presence of borers. Small mounds of excrement can be found along the stem and usually a slimy exudate is present. Later in the growing season, a hypertrophic condition develops at the base of the stem (Figure 3), and in severe infestations the stem is severed. Growth of the vines under these conditions sometimes continues by secondary roots from nodes along the vine, but the fruits are generally inferior in quality and quantity.

Borers were present in the vines from approximately July 4, when eggs of the first-appearing moths began to hatch, until harvest in early October. Thirty-eight borers were dissected from one plant that had not set fruit. Such an infestation would normally result in the death of the plant or the movement of some of the borers to a more adequate food supply. That borers do move when the food supply is depleted was demonstrated by infesting one of two caged plants with 100 field-collected eggs. Within 2 weeks, the uninfested plant became infested and eventually both plants died.

Although the borers were normally found in the basal 3 feet of stem, they were occasionally found in the leaf petioles, and in the mature fruits (Figure 4) when the vines had wilted in the fall. In a rare infestation, a first-instar larva bored into a leaf vein and by progressive feeding became established in the main stem of the seedling. On another occasion, a second-instar larva was dissected from a lateral root.

The mature borers form their cocoons at depths of 1 to 6 inches in the soil. The cocoon is tough, leathery, and covered with debris, gravel, and soil particles, so that it is almost indistinguishable from its surroundings. It varies considerably in shape and is 14 to 20 mm. long and 4 to 5 mm. wide at the widest end, where the head of the borer is situated usually (Figure 5). The winter is passed in this stage.

Pupa

The pupae are mahogany-brown and are 12 to 16 mm. long. Separation of the sexes in the pupal stage is not difficult; there is a double row of backward-projecting spines on segments 2 to 6 in the female and 2 to 7 in the male.

The pupa is formed within the cocoon during the spring or early summer. At maturity, the pupa forces the end of the cocoon and wriggles to the soil furface, where it assumes a vertical position. The adult then emerges through a T-shaped split on the anterodorsal surface of the thorax. Occasionally some cocoons are exposed by cultural practices, but the adults emerge without difficulty.

ACKNOWLEDGEMENTS

The author wishes to thank Miss K. E. Boyce, formerly of the Chatham Laboratory, who assisted in much of the insectary rearing. Thanks are also extended to J. W. McWade and D. V. Lalonde, of the Chatham Laboratory, for taking the photographs.

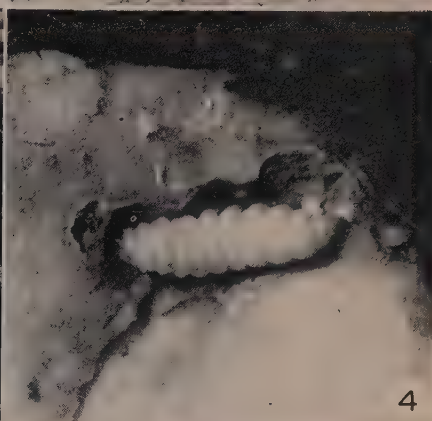


FIGURE 1. Eggs of the squash vine borer on the stem of seedling Golden Hubbard squash.
FIGURE 2. Wilting vines caused by heavy infestation of the borer.
FIGURE 3. Hypertrophic condition at base of squash stem caused by the borer.
FIGURE 4. Mature larva in fruit of Golden Hubbard squash.
FIGURE 5. Variations in size and shape of cocoons of the borer.

REFERENCES

1. Englehardt, G. P. The North American clear-wing moths of the family Aegeriidae. U.S. Natl. Mus. Bull. 190. 1946.
2. Friend, R. B. The squash vine borer, *Melittia satyriniformis* Hubner. Connecticut Agr. Expt. Sta. Bull. 328. 1931.
3. Harris, T. W. Insects. *In* New England Farmer 7 : 33-34. 1828.
4. Hervey, G. E. R., and H. C. Huckett. The squash vine borer. New York Agr. Expt. Sta. (Geneva). Circ. 127. 1932.
5. Howe, W. L. Biology and host relationships of the squash vine borer. J. Econ. Ent. 43 : 480-483. 1950.
6. MacNay, C. G., compiler. The Canadian Insect Pest Review 26. 1949.
7. Reed, E. B. Insects attacking the cucumber, melon, pumpkin and squash. Rept. Ent. Soc. Ontario, 1871, pp. 89-92. 1872.

BROWN FOREST-GREY WOODED SOIL SEQUENCE IN THE TEMISKAMING DISTRICT OF ONTARIO[1]

B. C. Matthews[2], D. W. Hoffman[3] and D. J. Eagle[4]

Guelph, Ont.

[Received for publication June 9, 1955]

ABSTRACT

On the basis of physical and chemical analyses (particle size distribution, bulk density, organic matter, pH, carbonates, exchangeable cations, cation exchange capacity, and total chemical composition) of genetic horizons of one Brown Forest soil, two Grey Wooded soils and one Podzolized Grey Wooded soil, it was concluded that the differences in profiles were related to differences in texture of the parent material. With a decrease in clay content of the parent material, the thickness of the horizons and the depth to free carbonates in the profiles increased and per cent base saturation decreased. The four profiles studied appear to represent segments in a hypothetical soil development sequence from Brown Forest through Grey Wooded to Podzolized Grey Wooded.

During the survey of the soils of the "Little Clay Belt" area in the District of Temiskaming, three kinds of profiles were found in well drained positions. Soils developed from fine textured calcareous water-laid materials were classified in Brown Forest, Grey Wooded or Podzol great soil groups on the basis of the kind, number and arrangement of major horizons. Upon consideration of the minor horizons and degree of profile development it was apparent that there was a range in profile characteristics from Brown Forest soils to Grey Wooded soils and from Grey Wooded soils to Podzol soils. The "intermediate" profiles seemed comparable to the intergrades that Stobbe (12) described for Grey-Brown Podzolic and related soils in eastern Canada.

The purpose of this study was to characterize, by physical and chemical analyses, the soil profiles representing points in the range from Brown Forest through Grey Wooded to Podzol-Grey Wooded intergrade soils.

DESCRIPTION OF THE AREA

Location

The District of Temiskaming is in Northern Ontario along the Ontario-Quebec border. The area from which the profile samples were taken is within the "Little Clay Belt" on about 47° 30′ N. latitude.

Geology

The Little Clay Belt is covered by sediments deposited by glacial Lake Barlow which was a contemporary of glacial lakes Ojibway (Great Clay Belt) in Northern Ontario and Agassiz in Southern Manitoba. Although the bedrock in most of the Little Clay Belt area is of Precambrian origin, the area from which the samples were taken was underlain by limestone of the Lockport, Medina and Trenton formations (8).

[1] Contribution from Department of Soils, Ontario Agricultural College, Guelph, Ontario, and Field Husbandry, Soils and Agricultural Engineering Division, Experimental Farms Service.
[2] Professor of Soils, Ontario Agricultural College.
[3] Pedologist, Experimental Farms Service.
[4] Technician, Ontario Agricultural College.

Three distinct beds of sediment, deposited one on top of the other, were found in the area. The deepest deposit was varved grey and brown clay like the parent materials of Profile 2. Above this, there was a deposit of brown clay material varying from zero to three feet in thickness and resembling the parent materials of Profile 1. The uppermost deposit of pale brown silt loam was 10 to 20 feet thick and resembled the parent materials of Profiles 3 and 4.

Climate

The mean annual precipitation of the area is 31.58 inches including 92 inches of mean annual snowfall. The mean annual temperature is 38° F. with a mean winter temperature of 9° F. and a mean summer temperature of 64° F. The average frost-free period is 110 days.

Vegetation

The natural vegetation consisted of predominantly balsam fir. As a result of fires, however, the coniferous cover has been replaced by aspen, poplar and white birch.

DESCRIPTION OF SOILS

Four sites were selected in unpastured woodlands on fine textured water-laid soil materials. The profiles were chose to represent the Dack, Haileybury, Evanturel and Blanche series.

Profile descriptions, taken at the time of sampling are presented below:

Profile No. 1—Dack clay

Ao — ½-0 inch of partially decomposed deciduous leaves and twigs.

A_1 — 0-4 inches of dark greyish brown (10 YR 4/2)* clay; fine sub-angular blocky; pH—6.3.

B_1 — 4-9 inches of dark greyish brown (10 YR 4/2) clay; medium sub-angular blocky; pH—5.5.

B_2 — 9-16 inches of dark brown (10 YR 4/3) clay; medium sub-angular blocky; pH—7.1.

C′ — 16-21 inches of brown (10 YR 5/3) clay; massive; calcareous; pH—7.9.

C″ — 21-27 inches; similar to C′. pH 7.9.

C‴— 27-33 inches, similar to C′. pH 8.0.

D — 33+ inches of yellowish brown (10 YR 5/4) clay; massive; varved; calcareous; pH 8.0.

Great Soil Group—Brown Forest.

Vegetation—poplar, birch.

Slope—4 per cent.

Location—Lot 7, Con. IV, Dack Township, Temiskaming District.

* Munsell Colour Notation taken on moist soil.

Profile No. 2—Haileybury silty clay.

Ao — ½-0 inch of partially decomposed leaves, twigs and needles.

A_1 — 0-2 inches of dark grey-brown (10 YR 4/2) silty clay; medium granular; pH—5.8.

A_2 — 2-5 inches of light brownish grey (2.5 Y 6/2) silty clay; weakly platy; pH—6.0.

B_1 — 5-9 inches of brown (10 YR 5/3) silty clay; coarse blocky; pH—5.9.

B_2 — 9-20 inches of brown (10 YR 4/3) clay; medium sub-angular blocky; pH 5.8.

B_3 — 20-25 inches of yellowish brown (10 YR 5/4) clay; weakly blocky, some varves; calcareous; pH 7.5.

C' — 25-32 inches of light grey (2.5 Y 7/2) and light olive brown (2.5 Y 5/4) clay; varved; calcareous; pH 7.9.

C'' — 32-40 inches of light grey (2.5 Y 7/2) and light olive brown (2.5 Y 5/4) silty clay; varved; calcareous; pH 7.9.

C'''— 40-46 inches, same as C'; pH 7.9.

Great Soil Group—Grey Wooded.

Vegetation—poplar, birch, spruce.

Slope—5 per cent.

Location—Lot 7, Con. IV, Kerns Township, Temiskaming District.

Profile No. 3—Evanturel silt loam.

Ao — ½-0 inch of partially decomposed deciduous leaves and twigs.

A_1 -- 0-2 inches of grey-brown (10 YR 5/2) silt loam; crumb; pH 6.1.

A_{21} — 2-7 inches of yellowish brown (10 YR 5/6) silt loam; very weakly platy; pH—5.6.

A_{22} — 7-13 inches of very pale brown (10 YR 8/3) silt loam; weakly platy; pH—5.5.

B_2 — 13-20 inches of yellowish brown (10 YR 5/4) silty clay loam; medium sub-angular blocky; pH—6.2.

B_3 — 20-25 inches of brownish yellow (10 YR 6/6) silt loam; slightly calcareous; pH—7.4.

C' — 25-32 inches of light brown (7.5 YR 6/4) silt loam; massive; calcareous; pH—8.0.

C'' — 32-40 inches, same as C', pH—8.3.

C'''— 40-46 inches; same as C'; pH—8.3.

Great Soil Group—Grey Wooded.

Vegetation—poplar.

Slope—5 per cent.

Location—Lot 10, Con. III, Evanturel Township, Temiskaming District.

Profile No. 4—Blanche silt loam.

Ao — ½-0 inch of partially decomposed deciduous leaves and twigs.

A_1 — 0-1 inch of dark grey (10 YR 4/1) silt loam, medium granular; pH—5.3.

A_2p— 1-3 inches of white (10 YR 8/2) silt loam; platy; pH—5.4.*

Bp — 3-6 inches of light yellowish brown (10 YR 6/4) silt loam; weakly platy; pH—5.4.*

A_2 — 6-16 inches of very pale brown (10 YR 8/3) silt loam; weakly platy; pH—5.6.

B_{21} — 16-26 inches of yellowish brown (10 YR 5/5) silt loam; medium sub-angular blocky; pH 6.2.

B_{22} — 26-34 inches of pale brown (10 YR 6/3) silty clay loam; medium sub-angular blocky; pH—6.5.

C′ — 34-40 inches of pale brown (10 YR 6/3) silt loam; massive; non-calcareous; pH—6.5.

C″ — 40-46 inches of pale brown (10 YR 6/3) silty clay loam; massive; non-calcareous; pH—6.9.

C‴— 46-50 inches of very pale brown (10 YR 7/4) silty clay loam; massive; slightly calcareous; pH—7.4.

C⁗— at 8 feet—same as C‴ but strongly calcareous; pH—8.0.

Great Soil Group—Grey Wooded (podzolized).

Vegetation—poplar.

Slope—2 per cent.

Location—Lot 11, Con. III, Evanturel Township, Temiskaming District.

* Horizons of a secondary podzol profile.

The variations in observable profile features among the four soils suggest a continuous variation from Dack to Haileybury to Evanturel to Blanche soil. This represents a transition from the Brown Forest soil through Grey-Wooded to Podzolized Grey Wooded soil. Such a profile sequence was suggested by Stobbe (12) and has been described in detail for Grey-Brown Podzolic soils by McCaleb and Cline (7).

EXPERIMENTAL METHODS

A large rectangular pit was dug and core samples for bulk density determination were taken from the central part of each genetic horizon of the profiles. Bulk samples of each horizon were collected, dried, and ground to pass through a 10-mesh screen. After thorough mixing, representative samples for analysis were taken from the main sample of each horizon and stored in a dessicator.

The soil cores were dried to constant weight at 105° C. and the bulk density was calculated by dividing the dry weight of the soil by the volume of the core. Mechanical analyses were made by the Bouyoucos hydrometer method (1). Organic matter of the surface horizon was destroyed in a muffle furnace before mechanical analysis.

The pH and cation exchange capacities were determined according to Peech (9), ammonia being determined by direction distillation using the Kjeldahl method. Organic matter determinations were made by Walkley's modification of the Schollenberger method (13). Exchangeable calcium and magnesium in the ammonium acetate extract were determined by the versenate method as outlined by Cheng, Lee, and Bray (2) using sodium diethyldithiocarbamate to remove interfering ions (3). Sodium and potassium were determined by means of the Barclay flame photometer using an internal standard.

Sodium carbonate fusion analysis was done according to the methods of Hillebrand and Lundell (6) except that calcium and magnesium in the leachate from the sesquioxide precipitation were determined by the versenate method (3). Sodium and potassium were brought into solution by treatment of a separate sample of soil with hydrofluoric acid followed by perchloric acid digestion (5). Final determination of sodium and potassium was made with a Barclay flame photometer.

Total carbonates were determined by the Schollenberger method (10).

RESULTS AND DISCUSSION

The carbonate analyses given in Table 1 indicate that the parent materials of the four soils contained approximately 15 per cent free lime.

TABLE 1.—PERCENTAGE BASE SATURATION, pH AND CARBONATE CONTENT OF GENETIC HORIZONS OF PROFILES

Horizon	Base saturation	pH	$CaCO_3$ equivalent	Horizon	Base saturation	pH	$CaCO_3$ equivalent
	%		%		%		%
		Dack				*Haileybury*	
A_1	99.5	6.3	0.11	A_1	82.6	5.8	0.05
B_1	83.0	5.5	0.02	A_2	71.5	6.0	0.03
B_2	100.0	7.1	0.16	B_1	78.5	5.9	0.03
C′	100.0	7.9	13.18	B_2	84.1	5.8	0.03
C″	100.0	7.9	15.76	B_3	100.0	7.5	2.06
C‴	100.0	8.0	16.80	C′	100.0	7.9	11.76
D	100.0	8.0	16.72	C″	100.0	7.9	15.24
				C‴	100.0	7.9	14.34
		Evanturel				*Blanche*	
A_1	60.4	6.1	0.18	A_1	55.8	5.3	0.00
A_{21}	44.3	5.6	0.03	A_{2p}	41.8	5.4	0.00
A_{22}	68.2	5.5	0.00	Bp	34.4	5.4	0.00
B_2	99.0	6.2	0.00	A_2	42.6	5.6	0.00
B_3	100.0	7.4	0.17	B_{21}	79.2	6.2	0.10
C′	100.0	8.0	10.66	B_{22}	98.8	6.5	0.11
C″	100.0	8.3	13.44	C′	91.5	6.5	0.09
C‴	100.0	8.3	15.44	C″	100.0	6.9	0.20
				C‴	100.0	7.4	0.73
				C⁗	100.0	8.0	13.22

It is reasonable to assume that the sola of the soils developed through a succession of genetic changes from material like that in the C horizons of the respective profiles. The depth to which free carbonates have been removed, therefore, is an indication of the intensity of leaching and presumably of weathering. In order of increasing degree of leaching, therefore, Dack was < Haileybury < Evanturel < Blanche.

Additional evidence of the degree of leaching is the trend in pH and percentage base saturation as shown in Table 1. The percentage base saturation of comparable horizons is highest in the Dack profile and lowest in the Blanche with Haileybury and Evanturel soils being intermediate. In view of the fact that all four soils have developed from sediments of the same glacial lake, and, therefore, have been exposed to weathering for the same period of time, the differences in base saturation and depth of leaching of carbonates are not due to differences in absolute age of the soils. Moreover, all soils occur within the same climatic area so that a difference in rainfall has not been a factor in causing the above differences. The Dack soil, however, was finer in texture than the Haileybury which in turn was finer than the Evanturel and Blanche soils. The increased clay content and probable decrease in permeability or increased run-off accounted for the trend toward decreased leaching in the finer textured soils. The explanation of the increased leaching of the Blanche soil as compared to

TABLE 2.—CATION EXCHANGE CAPACITY AND EXCHANGEABLE CATIONS OF GENETIC HORIZONS OF PROFILES

Horizon	C.E.C. m.e./ 100 gm.	Ca m.e./ 100 gm.	Mg m.e./ 100 gm.	K m.e./ 100 gm.	Horizon	C.E.C. m.e./ 100 gm.	Ca m.e./ 100 gm.	Mg m.e./ 100 gm.	K m.e./ 100 gm.
	Dack					*Haileybury*			
A_1	23.01	18.92	3.54	0.50	A_1	24.79	16.86	3.19	0.46
B_1	27.55	17.98	4.20	0.66	A_2	11.95	7.00	1.24	0.29
B_2	29.19	24.01	5.16	0.40	B_1	22.39	12.54	4.60	0.43
C′	27.73	36.56	5.51	0.43	B_2	28.19	16.06	7.19	0.48
C″	28.51	37.59	5.78	0.43	B_3	22.03	19.03	7.11	0.38
C‴	26.39	36.82	4.44	0.40	C′	21.08	28.70	4.71	0.39
D	22.59	23.69	5.43	0.39	C″	9.45	9.20	5.20	0.18
					C‴	14.49	23.63	5.96	0.30
	Evanturel					*Blanche*			
A_1	9.14	4.82	1.42	0.27	A_1	14.28	6.21	1.54	0.22
A_{21}	5.80	1.71	0.69	0.17	A_{2P}	8.37	2.65	0.69	0.16
A_{22}	3.57	1.54	0.85	0.05	Bp	7.86	2.10	0.44	0.17
B_2	10.11	5.91	3.93	0.15	A_3	6.16	1.97	0.54	0.12
B_3	9.78	6.76	3.81	0.12	B_{21}	14.92	8.08	3.52	0.24
C′	6.10	7.15	3.62	0.10	B_{22}	13.74	8.74	4.62	0.20
C″	6.25	14.17	3.12	0.10	C′	13.84	8.05	4.36	0.26
C‴	5.72	13.74	2.60	0.12	C″	11.34	7.54	4.75	0.22
					C‴	11.60	8.55	5.58	0.21
					8′	8.89	8.86	4.51	0.15

TABLE 3.—PARTICLE SIZE DISTRIBUTION OF GENETIC HORIZONS OF PROFILES

Horizon	Sand	Silt	Clay	Horizon	Sand	Silt	Clay
	%	%	%		%	%	%
		Dack				*Haileybury*	
A_1	8.4	32.6	59.0	A_1	9.6	47.6	42.8
B_1	4.8	16.8	78.4	A_2	7.2	51.4	41.4
B_2	8.4	6.8	84.8	B_1	6.0	36.0	58.0
C′	4.3	8.1	87.6	B_2	12.2	19.8	68.0
C″	3.4	7.5	89.1	B_3	11.0	29.0	58.0
C‴	7.6	2.6	89.8	C′	8.4	21.8	69.8
D	4.6	32.0	63.4	C″	4.7	63.3	32.0
				C‴	2.8	34.2	63.8
		Evanturel				*Blanche*	
A_1	16.7	68.9	14.4	A_1	20.4	58.8	20.8
A_{21}	15.3	69.9	14.8	A_{2p}	19.2	60.4	20.4
A_{22}	11.1	74.5	14.4	Bp	15.4	63.0	21.6
B_2	12.2	59.6	28.2	A_2	14.6	64.2	21.2
B_3	7.4	68.5	24.1	B_{21}	12.4	61.4	26.2
C′	8.4	70.8	20.8	B_{22}	11.4	52.6	36.0
C″	11.4	63.4	25.2	C′	14.7	60.5	24.8
C‴	12.6	66.0	21.4	C″	17.5	52.9	29.6
				C‴	14.9	51.9	33.2
				8′	5.6	67.3	27.1

the Evanturel is not clearly apparent as the Blanche was finer in texture than the Evanturel soil.

The cation exchange capacity, shown in Table 2, of the Dack profile increased from the A_1 horizon downward because of the increase in clay content, shown in Table 3. The increase in clay offset the decrease in organic matter content shown in Table 4. In the other soils, the cation exchange capacity was lowest in the A_2 and C horizons and highest in the A_1 and B horizons in conformity with the distribution of clay and organic matter. The horizons of the Evanturel and Blanche soils had lower cation exchange capacities than comparable horizons of the other soils because of a lower clay content. The trends in cation exchange capacity with depth were remarkably similar in the Haileybury, Evanturel and Blanche soils. In this respect, the C″ horizon of the Haileybury soil resembled the C horizons of the Evanturel and Blanche soils more closely than it did the C′ and C‴ horizons of the same profile.

TABLE 4.—ORGANIC MATTER CONTENT OF GENETIC HORIZONS OF PROFILES

Horizon	Per cent	lb./sq.ft. cross-section	Horizon	Per cent	lb./sq. ft. cross-section
	Dack			*Haileybury*	
A_1	6.4	1.74	A_1	6.4	0.88
B_1	1.1	0.42	A_2	1.6	0.37
B_2	0.95	0.49	B_1	0.67	0.21
C′	0.66	0.26	B_2	0.37	0.33
C″	0.48	0.22	B_3	0.75	0.56
C‴	0.48	0.22	C′	0.29	0.25
D	0.37	0.20	C″	0.27	0.13
			C‴	0.27	0.09
Total for X-section to 40″	3.55			2.60	
Total per acre to 40″	155,000			115,000	
	Evanturel			*Blanche*	
A_1	1.53	0.17	A_1	5.2	0.27
A_{21}	0.78	0.25	A_{2p}	0.95	0.14
A_{22}	0.23	0.11	Bp	0.93	0.18
B_2	0.23	0.14	A_2	0.22	0.16
B_3	0.46	0.17	B_{21}	0.21	0.18
C′	0.31	0.17	B_{22}	0.21	0.13
C″	0.31	0.20	C′	0.32	0.16
C‴	0.23	0.11	C″	0.27	0.13
			C‴	0.24	0.07
Total for X-section to 40″	1.11			1.22	
Total per acre to 40″	49,000			53,000	

In conformity with the trends in cation-exchange capacity, there were fewer exchangeable bases in the Evanturel and Blanche soils than in the Haileybury and Dack soils. Again the C″ horizon of the Haileybury was similar in this respect to the C horizons of the Evanturel and Blanche soils. In the Dack soil, the amount of exchangeable magnesium increased steadily with depth although the exchangeable calcium was at a minimum in the B_1 horizon. In the other three soils, the minimum of exchangeable calcium, magnesium and potassium was in the A_2 horizon. There was a maximum in exchangeable potassium in the B_1 horizon of the Dack profile.

Table 3 gives the particle size distribution of the genetic horizons of the four soils studied. The Dack and Haileybury were clay types and the

Evanturel and Blanche were silt loam types. The texture of the Dack profile became uniformly finer with depth down to and including the C horizons. There was a marked decrease in clay in the D horizon which texturally resembles the C′ and C‴ horizons of the Haileybury soil. No clay maximum was evident in the Dack profile although it was quite evident in the other three profiles. The C″ horizon of the Haileybury soil resembled the C horizons of the Evanturel soil in respect to particle size distribution. In view of the fact that all of these soils occurred in the same glacial lake plain, some intermixing and layering of soil materials is to be expected. The Evanturel and Blanche soils were coarser in texture than the other two soils. The depth at which the clay maximum occurred in the profile increased from the Haileybury to Evanturel to Blanche profiles.

The size of the clay maximum in the B_2 horizon and the depth of its occurrence in the profile tended to increase as the loss of exchangeable bases and acidity increased. Moreover, the clay maximum occurred immediately above the point at which carbonates occurred in all soils. These observations are similar to those of McCaleb and Cline (8) in regard to a development sequence involving Grey-Brown Podzolic soils. If it be assumed that the clay maximum was a result of clay movement in suspension from the A horizons to the B, the absence of carbonates and an acid reaction are prerequisites for such a translocation. Acidity is an important factor governing the peptization of clays in the A horizon and isoelectric precipitation in the B horizon. On the other hand, if it is assumed that the clay maxima are due to clay synthesis from silicates in situ, the absence of carbonates would also be a prerequisite in view of Stevens' (11) reasoning that carbonates inhibit weathering of silicate minerals. Available data does not permit conclusions regarding the process of clay accumulation in the B horizon. It is apparent, nevertheless, that in the soils studied here, the thickness of the eluviated horizons and the depth of the clay maximum in the solum increased with a decrease in base saturation and pH which probably was a function of permeability of the soil materials.

It is evident from Table 4 that the organic matter content of these soil profiles calculated using bulk density values in Table 5 decreased with

TABLE 5.—BULK DENSITIES OF GENETIC HORIZONS OF PROFILES

Horizon	Dack	Horizon	Haileybury	Horizon	Evanturel	Horizon	Blanche
A_1	1.30	A_1	1.32	A_1	1.08	A_1	1.00
B_1	1.47	A_2	1.49	A_{21}	1.24	A_{2p}	1.34
B_2	1.42	B_1	1.47	A_{22}	1.46	Bp	1.25
C′	1.50	B_2	1.55	B_2	1.62	A_2	1.38
C″	1.48	B_3	1.60	B_3	1.44	B_{21}	1.68
C‴	1.45	C′	1.53	C′	1.47	B_{22}	1.52
D	1.48	C″	1.54	C″	1.52	C′	1.58
		C‴	1.55	C‴	1.51	C″	1.59
						C‴	1.51

TABLE 6.—CHEMICAL COMPOSITION OF GENETIC HORIZONS OF THE PROFILES

Horizon	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O
				Dack			
A_1	65.9	17.1	7.4	2.3	1.5	1.9	3.3
B_1	62.0	20.4	8.9	1.7	1.3	2.0	3.5
B_2	59.1	22.5	9.9	2.1	1.6	2.0	3.7
C_1	53.1	20.1	9.4	9.8	2.6	1.9	3.5
C_{11}	53.3	20.1	8.9	10.8	3.0	1.3	2.7
C_{111}	52.3	19.6	8.3	11.4	4.4	1.7	2.8
D	62.4	19.5	6.8	4.8	2.2	2.3	2.6
				Haileybury			
A_1	70.9	16.0	5.1	2.5	2.0	3.0	3.2
A_2	72.5	15.4	4.9	2.2	2.0	2.8	2.9
B_1	66.2	17.5	7.3	1.9	2.1	3.0	3.1
B_2	63.3	20.1	8.5	1.9	2.1	2.2	3.1
B_3	64.1	17.9	7.6	2.8	2.6	2.2	2.9
C_1	59.5	17.9	7.0	7.7	3.8	2.4	2.9
C_{11}	68.5	15.6	4.7	4.1	2.2	3.0	2.3
C_{111}	59.3	16.0	6.4	8.4	3.3	2.4	2.7
				Evanturel			
A_1	75.2	13.4	2.4	3.0	1.2	3.0	2.3
A_{21}	73.9	14.2	3.4	2.9	1.3	2.9	2.3
A_{22}	75.4	13.3	3.1	3.0	1.3	3.1	2.2
B_2	71.9	15.0	4.2	3.0	1.4	3.1	2.1
B_3	72.4	14.3	3.9	3.0	1.5	3.1	2.5
C_1	68.8	13.1	3.8	6.3	2.5	3.0	2.3
C_{11}	66.5	12.7	3.8	8.0	3.9	2.9	2.2
C_{111}	67.0	12.7	3.8	8.0	3.7	3.0	2.1
				Blanche			
A_1	76.7	12.3	2.8	2.0	0.8	2.7	2.6
A_2p	76.4	12.8	2.6	2.0	0.9	2.8	2.7
Bp	74.3	13.7	3.2	2.2	1.0	2.8	2.5
A_2	73.2	14.2	3.2	2.2	1.3	3.0	2.5
B_{21}	69.4	16.0	5.5	2.3	1.3	2.8	2.6
B_{22}	69.9	16.6	5.0	2.4	1.3	2.9	2.5
C_1	69.3	16.4	5.1	2.4	1.9	2.7	2.5
C_{11}	71.1	15.6	4.8	2.7	1.4	2.8	2.3
C_{111}	70.5	16.3	4.5	2.9	1.4	2.6	2.2
8_1	65.9	15.0	4.0	6.6	3.5	2.4	2.1

increasing acidity or leaching except in the Blanche soil. Such a trend would be expected in view of the decrease in base saturation which, in turn, tends to decrease the effectiveness of the vegetation in producing organic material. The total organic matter in the Grey Wooded profiles was much less than that normally found in Grey-Brown Podzolic profiles (7).

The total chemical analyses of genetic horizons are given in Table 6.

The following trends in analyses with depth were evident in each of the profiles:

(1) Silica was at a mazimum in the A_2 horizons, intermediate in the B horizons and sharply decreased from B to C horizons due to dilution effect of the carbonates in the C horizon.

(2) Iron and alumina percentages were lowest in the A_2 horizons and highest in the B horizons.

(3) Calcium oxide percentages were lowest in A_2 horizon, slightly higher in the A_1, but increased markedly from A_2 to B to the C horizons.

(4) Magnesium oxide percentages increased gradually with depth with a marked increase at the depth of occurrence of carbonates.

(5) Sodium and potassium were at a minimum in the C horizons of all profiles.

In general, the trends noted above became more evident with increasing acidity of the profile i.e., from Dack to Blanche profiles.

There was a trend toward decreasing SiO_2/Al_2O_3 ratios, as shown in Table 7, with depth in each of the profiles and from the Blanche to Dack

TABLE 7.—MOLECULAR RATIOS OF GENETIC HORIZONS OF PROFILES

Horizon	SiO/Al_2O_3				CaO/Al_2O_3			
	Dack	Haileybury	Evanturel	Blanche	Dack	Haileybury	Evanturel	Blanche
A_1	6.53	7.52	9.16	10.58	0.230	0.283	0.392	0.296
A_{2P}				10.12				0.284
Bp				9.20				0.292
A_{21}			8.49				0.357	
A_{22}			9.27				0.394	
A_2		7.97		8.75		0.259		0.282
B_1	5.16	6.42			0.152	0.197		
B_2	4.35	5.34	7.83	7.36	0.165	0.172	0.350	0.261
B_3		5.41	8.27			0.284	0.367	
C_1	4.46	5.63	8.59	7.14	0.882	0.781	0.841	0.263
C_{ii}	4.48	7.44	8.55	7.74	0.973	0.478	1.43	0.315
C_{iii}	4.58	6.30	8.60	7.35	1.06	0.953	1.43	0.322
C_{iiii}				7.47				0.781
D	5.43				0.447			
	SiO_2/Fe_2O_3				Fe_2O_3/Al_2O_3			
A_1	23.63	37.0	83.5	72.8	0.276	0.203	0.110	0.145
A_{2P}				76.1				0.135
Bp				59.8				0.154
A_{21}			55.2				0.154	
A_{22}			64.7				0.143	
A_2		39.3		59.0		0.203		0.148
B_1	18.49	24.1			0.279	0.266		
B_2	15.88	19.8	45.5	33.6	0.274	0.270	0.172	0.219
B_3		22.2	49.4			0.270	0.167	
C_1	15.02	22.6	48.2	37.2	0.287	0.249	0.178	0.192
C_{ii}	15.92	38.8	46.5	39.4	0.282	0.192	0.184	0.196
C_{iii}	16.96	24.6	46.8	41.7	0.270	0.255	0.184	0.176
C_{iiii}				43.8				0.170
D	24.38				0.222			

profiles. Apparently with increasing acidity, there is an increase in weathering of aluminum-bearing minerals relative to quartz. The SiO_2/Al_2O_3 ratios of the parent materials increased from Dack to Evanturel soils and then decreased in the Blanche soil. There was a decrease in Fe_2O_3/Al_2O_3 ratios from Dack to Evanturel profiles i.e. with increasing acidity. In the Blanche profiles, however, the ratio increased slightly. At high pH, weathering of ferromagnesian minerals must proceed more rapidly than the weathering of aluminosilicates. At low pH, however, iron was weathered from the profile less rapidly than aluminum. The SiO_2/Fe_2O_3 ratios indicated accelerated loss of iron relative to silica in the surface horizons with increasing degree of weathering as reflected by increasing acidity. Within all profiles, the SiO_2/Fe_2O_3 ratios indicated an accumulation of iron relative to silica in the B_2 horizons. Moreover, there was a secondary increase in iron in the Bp horizon relative to the A_{2p} horizon of the Blanche profile. In both the B_2 and Bp horizons, iron apparently is accumulating during genesis. The extent of the accumulation of iron in the B_2 horizons increased from the Dack to the Blanche profiles.

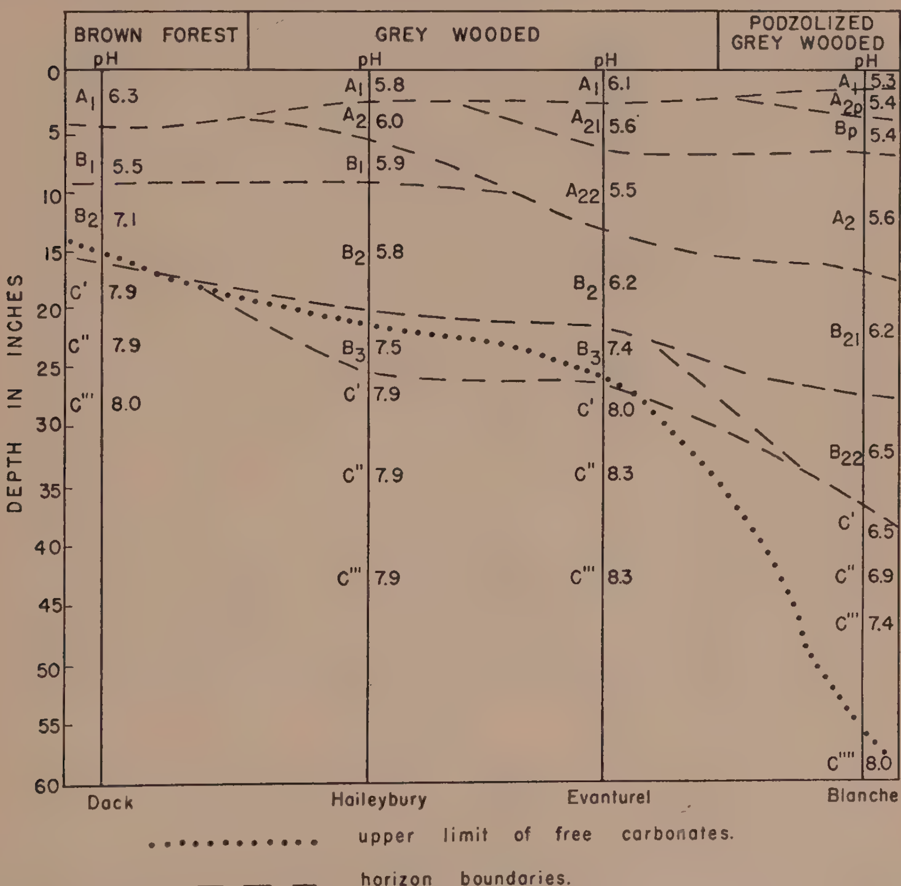


FIGURE 1. Diagrammatic representation of trends in profile characteristics in the Brown Forest-Grey Wooded soil sequence.

INTERPRETATION OF SOIL GENESIS

On the basis of the field and laboratory data on the morphology of the Dack, Haileybury, Evanturel and Blanche profiles, it is suggested that these soils represent segments of a soil development sequence. Some of the major morphological characteristics that vary within the sequence are summarized in Figure 1.

Although there was some evidence of geological unconformity in the C″ horizon of the Haileybury soil, it may be generally assumed that all of the soils developed from water-laid materials containing about 15 per cent carbonates. The depth and extent of loss of carbonates and bases, however, increased from left to right in the sequence shown in Figure 1. This could be a result of increased time of exposure of respective soil materials. In fact, however, the glacial lake that deposited the materials of all four soils receded from all parts of the area at about the same time. It was concluded, therefore, that the loss of bases was function of the permeability of the soil materials as indicated by the particle size distribution.

On the basis of Stevens' (20) conclusion that carbonates inhibit weathering of silicates, one would expect the accumulation of clay, the loss and/or accumulation of sesquioxides (hence the kind and thickness of genetic horizons) to be a function of carbonate leaching. With increased loss of bases, the vegetation becomes less effective in returning bases and organic material to the surface. Moreover, the melanization of organic matter is slow under relatively cool climate and reduced earthworm activity. As shown in Figure 1, therefore, with decreasing base saturation and pH of the sola, the A_1 horizon became thinner and the total organic matter content decreased.

It was apparent that some of processes of soil development active in this Grey Wooded soil zone are the same as those considered active in the Grey-Brown Podzolic zone (4, 12). The relative rates of the processes undoubtedly differ and lead to the different profile development.

It cannot be assumed a priori that the Dack profile, for instance, was only a stage in the succession of genetic changes and that it will develop a Haileybury, Evanturel and eventually a Blanche profile. It is entirely possible that the impermeability of the materials combined with return of bases in the leaf litter and erosion of soil from the surface may maintain the Dack type of profile indefinitely. In other words, any of the profiles studied may actually have been in equilibrium with its environment and unless that environment changes, the soil could not develop further in the sequence.

CONCLUSIONS

On the basis of the field descriptions, and the trends in particle size distribution, pH, exchange capacities, and exchangeable cations, and total chemical analysis among the profiles studied, it was concluded that the Dack-Haileybury-Evanturel-Blanche soils could represent

segments of a Brown Forest-Grey Wooded-Podzol soil development sequence. The base saturation and depth of leaching of carbonate in the profiles were considered to be a function of the texture of the soil as it affected permeability and were not a function of time. The proposed soil development sequence in the Grey Wooded zone is similar to that in the Grey-Brown Podzolic zone.

REFERENCES

1. Bouyoucos, G. J. Acecalibration of the hydrometer method for making mechanical analyses of soils. J. Agron. 43 : 434-438. 1951.
2. Cheng, K. L., Kwang Lee, and Roger H. Bray. Determination of calcium and magnesium in soil and plant material. Soil Sci. 72 : 449-558. 1951.
3. Cheng, K. L., S. W. Melsted, and Roger H. Bray. Removing interfering metals in the versenate determination of calcium and magnesium. Soil Sci. 75 : 37-40. 1953.
4. Cline, Marlin G. Profile studies of normal soils of New York: I. Soil profile sequences involving brown forest, grey-brown podzolic and brown podzolic soils. Soil Sci. 68-259-272. 1949.
5. Corey, Richard B., and M. L. Jackson. Silicate analysis by a rapid semi-micro-chemical system. Anal. Chem. 25 : 624-628. 1953.
6. Hillebrand, W. F., and G. E. F. Lundell. Applied inorganic analysis. John Wiley and Sons, Inc., New York. 1929.
7. McCaleb, Stanley B., and Marlin G. Cline. Profile studies of normal soils in New York: III. Physical and chemical properties of brown forest and grey-brown podzolic soils. Soil Sci. 70 : 315-328. 1950.
8. Moorhouse, W. W. Geology of the Bryce-Robillard Area. Report, Ontario Department of Mines, Toronto. Vol. 50 : 1-46. 1941.
9. Peech, M., *et al.* Methods of soil analysis for soil fertility investigations. U.S.D.A. Cir. 575. 1952.
10. Schollenberger, C. J. Determination of carbonates in soil. Soil Sci. 59 : 57-63. 1945.
11. Stevens, R. E. Study on the alkalinity of some silicate minerals. U.S. Geol. Survey Prof. Paper 185A. 1934.
12. Stobbe, P. C. The morphology and genesis of the grey-brown podzolic and related soils of Eastern Canada. Proc. Soil Sci. Soc. Am. 16 : 81-84. 1952.
13. Walkley, Allan. A critical examination of a rapid method for determining organic carbon in soils—Effect of variations in digestion conditions and of inorganic soil constituents. Soil Sci. 63 : 251-264. 1947.

THE RELATIONSHIP BETWEEN AVAILABLE SOIL MOISTURE LEVELS AND POTATO YIELDS[1]

J. M. Fulton and H. F. Murwin

Canada Department of Agriculture, Harrow, Ontario

[Received for publication August 16, 1955]

ABSTRACT

Irrigation water was applied to early potatoes when the available soil moisture level (6 inches below the surface) dropped to the arbitrary levels of 25, 50 and 75 per cent. It is shown that irrigation water applied to early potatoes when the available level reached 75 per cent was no more effective than irrigation when the available level in the soil was allowed to drop to 50 per cent. Irrigation at the 50 per cent level produced higher yields than irrigation at the 25 per cent level. Under conditions of these experiments the increase in yield was a result of increased tuber size rather than an increased number of potatoes.

INTRODUCTION

Efficient use of water for supplemental irrigation demands a thorough knowledge of the soil and its moisture characteristics and the relationship between these characters and plant growth. Veihmeyer and Hendrickson (4, 8) working with tree fruits in California point out that "Experiments at Davis indicate that there is no outstanding response in either growth or yield to irrigation water applied while the soil moisture is above the permanent wilting percentage". They report that the growth of pear fruits was not retarded until the available moisture in the top 6 feet has been reduced to the permanent wilting percentage. Magness, Degman and Furr (7) report that there was no reduction in the rate of apple growth until the driest part of the root zone reached the permanent wilting percentage. Lehane and Staple (6) have prepared moisture release curves for seven different soils and state that "the moisture release curves explain why, under field conditions, all the moisture held by the lighter textured soils between field capacity and the wilting point may appear to be equally available to crops".

Aldrich and Work (1), however, report that the growth rate of Anjou pears was markedly slowed down well before the available moisture in the root zone reached the permanent wilting percentage. They recommend frequent light applications of water in order to maintain the available moisture above the 60 per cent level. Work and Lewis (9) suggest the soil moisture in areas immediately adjacent to the roots may be reduced to the permanent wilting percentage while rather large volumes of soil farther away may still contain considerable available moisture. If the rate of lateral movement is slower than transpiration the plant will wilt. Bonnen, McArthur, Magee and Hughes (2), working in the high plains area of Texas, report that best production of Irish potatoes is obtained when the soil is kept moist continuously from the time of last cultivation until harvest. This is accomplished by irrigating every 5 to 7 days.

Bradley and Pratt (3), working in New York State, found that when the available moisture at the 6-inch depth was not allowed to fall below 50

[1] Contribution from the Field Husbandry Division, Experimental Farms Service, Department of Agriculture, Ottawa, Canada.

per cent potato yields were higher in two cases out of three than when the level fell to 25 per cent before irrigation. Hill and Palmer (5) report: "Potato plants should be kept in active growing condition from emergence to harvest. At Lethbridge it is necessary to irrigate lightly every three weeks during the growing season, extending or shortening this period depending upon rainfall".

MATERIALS AND METHODS

The experimental data used in this report are from two separate experiments conducted at Harrow in each of two years. The experiments were established on the well drained Fox sandy loam soil at the Harrow Station in 1953 and continued with minor changes in 1954. In both cases Irish Cobbler potatoes were grown in plots 40 feet in length and 51 feet in width to accommodate 17 rows. The irrigation pipe and sprinklers were set up between the eighth and ninth potato rows. The second and third rows on each side of the sprinkler line were harvested for yield purposes. Since rotary sprinklers were used the water application was not uniform over the width of the plot but good distribution was obtained lengthwise. The irrigation system was calibrated so that the second and third row on each side of the sprinkler line received the desired amount of water. Three replications were used in each case and all data were analysed statistically.

When the percentage of available soil moisture fell to the arbitrary levels (25, 50 and 75 per cent) sufficient irrigation water was applied to bring the soil to field capacity. Available moisture levels were determined by means of the Bouyoucos moisture meter with gypsum blocks placed in the yield rows at a depth of 6 inches below the soil surface. The irrigation treatments were as follows:

1. Check—No irrigation.
2. Irrigation to maintain available soil moisture above the 25 per cent level.
3. Irrigation to maintain available soil moisture above the 50 per cent level.
4. Irrigation at a soil moisture tension of 700 cm. of water using the Irrometer type of tensiometer (approximately 75 per cent available).

Treatment No. 4 was not included in the same experiment as Treatments 1, 2 and 3 and therefore cannot be compared with them statistically. However, in 1954 it has been compared statistically with a second series of plots irrigated at 50 per cent available moisture level.

Ten hill samples were dug in rows adjacent to the yield rows prior to harvest in order to get an estimate of the effect of irrigation treatment on the number of tubers set. The potatoes harvested from the four yield rows were graded and the yields calculated as bushels of marketable potatoes per acre. The crop was planted early in April each year and harvested July 7 in 1953 and July 12 in 1954.

EXPERIMENTAL RESULTS

The effect of the irrigation treatments applied upon the total number of tubers set is shown in Table 1. Although the total number of tubers set per hill was not affected by the irrigation treatments applied it should be

TABLE 1.—THE EFFECT OF AVAILABLE MOISTURE LEVEL ON TUBER SET

Available moisture level	Total tubers in ten hills*		No. 1 size tubers in ten hills*	
	1953	1954	1953	1954
Check—No irrigation	77	76·6	23·5	12·2
25% available	87	76·8	45·5	16·3
50% available	84	85·9	51·5	23·5
L.S.D. at 5%	N.S.	N.S.	8·9	5·8

* Mean of three replications.

TABLE 2.—THE EFFECT OF AVAILABLE MOISTURE LEVELS ON YIELD OF POTATOES (DATA ARE MEANS OF THREE REPLICATES)

Available moisture level	Yield in bushels per acre	
	1953	1954
Check—No irrigation	140·9	93·5
25% available	230·2	162·5
50% available	267·2	212·6
L.S.D. at 5%	30·6	33·8
75% available	278·3	239·4
50% available		219·3
L.S.D. at 5%		40·3

pointed out that available moisture was above 50 per cent until about the time of first tuber formation in both years so that none of the plots was irrigated until within a few days of first tuber formation. In 1953 the plots under both irrigation treatments contained a greater quantity of No. 1 size tubers per hill than the non-irrigated plots. In 1954 the number of large tubers was increased by irrigation at 50 per cent available soil moisture.

Table 2 presents the yield data as related to available moisture levels. In both years irrigation to maintain available soil moisture above the 50 per cent level resulted in higher potato yields than irrigation to maintain the level above 25 per cent. Irrigation to maintain the available soil moisture supply above the 25 per cent level produced much higher yields than no irrigation at all. In 1954 the yields from the 75 per cent available moisture plots are compared with those from a second series of plots irrigated to maintain available moisture above 50 per cent. From the limited data available it appears that maintenance of the available moisture above 50 per cent produced yields equal to that obtained by keeping the soil moisture above 75 per cent available.

Table 3 reports the average amount of water used by the crop in inches per day during the period of active growth which started about May 20 and concluded at harvest. The water use rate per day was calculated by dividing the total amount of water received by each plot during the period by the number of days. It can be seen that irrigation at the 50 per cent available level increased yields as compared to the 25 per cent treatment.

TABLE 3.—THE EFFECT OF MAINTENANCE OF DIFFERENT AVAILABLE MOISTURE LEVELS ON AVERAGE WATER USE PER DAY DURING PERIOD OF ACTIVE GROWTH*

Available moisture level	Mean water use in inches per day	
	1953	1954
Check	0·06	0·06
25% available	0·13	0·10
50% available	0·14	0·11
75% available	0·15	0·15

* May 25 to harvest.

TABLE 4.—THE EFFECT OF MAINTAINING DIFFERENT AVAILABLE MOISTURE LEVELS ON THE NUMBER OF IRRIGATIONS REQUIRED, THE IRRIGATION INTERVAL AND THE TOTAL WATER USED

	Year	Check	Available moisture levels maintained		
			25%	50%	75%
Number of irrigation applications	1953	0	3	5	6
	1954	0	2	4	7
Average irrigation interval (days)	1953		10	5·5	5·2
	1954		13	8·0	4·5
Irrigation water used (inches)	1953	0	2·97	3·30	3·96
	1954	0	1·98	2·64	4·62

However, the water use rate was very similar. Thus it would seem that timing of irrigation applications may be just as important as using correct amounts, or even more so.

In 1953 it was found that the proper irrigation interval was either 5 or 6 days and averaged 5·5 days as shown in Table 4. In 1954 the irrigation interval was 8 days in every case. The difference in irrigation interval between the two years does not appear to be accounted for by differences in weather conditions since the mean temperature for May and June was very similar in both years and the rainfall was slightly higher in 1953. It is the opinion of the authors that the electrical resistance units had picked up some soluble salts through continued use resulting in recorded readings being somewhat higher than actual conditions. Plots irrigated at the 75 per cent level do not reflect these effects because the tensiometer was used as the measuring device on these plots.

Preliminary work on scheduled irrigation in 1954 indicated that 1 inch of water (rainfall included) applied every 7 days was just as effective for early potatoes grown on the Fox sandy loam as the use of soil moisture measuring devices. Extending the irrigation interval to ten days and applying 1½ inches of water was somewhat less effective.

DISCUSSION AND CONCLUSIONS

The results presented in this paper support the contention of several workers (1, 2, 3, 7) that tuber growth is drastically slowed down as the available moisture level drops even though the root zone still contains a

considerable supply of available moisture. Under the conditions of these experiments the increase in yield of potatoes grown under irrigation was due to an increase in tuber size rather than an increase in the number of tubers set. It has been shown that for best early potato production the available moisture supply 6 inches below the surface must not fall below the 50 per cent level. This agrees with the conclusions of Bradley and Pratt (3) working in New York State. However, since the roots may have been feeding in wetter soil below the 6 inches or in drier soil above the 6-inch depth it cannot be concluded that potatoes grow best when the available moisture in the whole root zone is allowed to drop to 50 per cent before irrigation. In other words, if the available moisture level is specified the depth of measurement must also be specified, but since potatoes root to a depth of at least 6 inches and yield is adversely affected if available moisture is below 50 per cent at this level it becomes obvious that soil moisture is not equally available from field capacity to the wilting point.

In order to maintain the 50 per cent level of availability rather frequent light applications are required on the Fox sandy loam at Harrow. It appears that the irrigation interval will range from about 5 to 8 days. It was found when irrigation water was applied to keep the available moisture above the 50 per cent level that the average water use per day during the period of most active growth was 0·14 inches in 1953 and 0·11 inches in 1954. It would seem that further experimentation might well show the way to an irrigation program which could be based on the water use rate of the crop and a specified irrigation interval.

Since the soil itself acts as a reservoir of available water and a slight deviation from 50 per cent availability may not be serious, it would seem that an irrigation program which supplies a total of about 0·90 inches of water (including rainfall) every 7 days may be quite satisfactory for early potatoes grown on Fox sandy loam soil.

REFERENCES

1. Aldrich, W. W., and Arch Work. Preliminary report of pear tree responses to variations in available soil moisture in clay adobe soil. Am. Soc. Hort. Sci. Proc. 29: 181-187. 1953.
2. Bonnen, C. A., W. C. McArthur, A. C. Magee, and W. F. Hughes. Use of irrigation water on the high plains. Bull. 756, Texas Agr. Expt. Station, College Station, Texas. 1952.
3. Bradley, George A., and Arthur J. Pratt. Irrigate to make a crop—not to save it. Farm Research Vol. XX, 2, April 1954. Cornell University, Ithaca, N.Y.
4. Hendrickson, A. H., and F. J. Veihmeyer. Irrigation experiments with pears and apples. Bull. 667, University of California, Berkeley, Calif. 1942.
5. Hill, K. W., and A. E. Palmer. Irrigation farming in southern Alberta. Pub. 883, Experimental Station, Lethbridge, Alta. 1953.
6. Lehane, J. J., and W. J. Staple. Water retention and availability in soils related to drought resistance. Can. J. Agr. Sci. 33: 265-273. 1953.
7. Magness, J. R., E. S. Degman, and J. R. Furr. Soil moisture and irrigation investigations in eastern apple orchards. Tech. Bull. 491, U.S.D.A. 1935.
8. Veihmeyer, F. J., and A. H. Hendrickson. Essentials of irrigation and cultivation of orchards. Circ. 50, University of California, Berkeley, Calif. 1950.
9. Work, R. A., and M. R. Lewis. The relation of soil moisture to pear tree wilting in heavy clay soil. J. Am. Soc. Agron. 28: 124-134. 1936.

FIELD STUDIES ON THE INHERITANCE OF RESISTANCE TO RUST IN THE CULTIVATED SUNFLOWER (*HELIANTHUS ANNUUS* L.)[1]

Eric D. Putt[2] and Emilio Rojas M.[3]

[Received for publication July 18, 1955]

ABSTRACT

The inheritance, under field conditions, of rust resistance of one sunflower line, 953-102-1-1-22, selected from the natural cross California Oilseed × Texas Wild Annual is reported. Six crosses were studied using three lines, differing in their degree of susceptibility, as female parents and single plants within the 953-102-1-1-22 line as males. The F_2 and F_4 segregating progenies were grown at Morden, Manitoba, in different seasons. The F_3 segregating progenies, except for a few, were grown at La Molina, Peru. Decision between resistant and susceptible plants was based on per cent infection at Morden and on pustule type at La Molina.

The results indicate that the resistance is dominant and inherited on a monofactorial basis. Chi-square tests showed good homogeneity of the data with respect to total populations of the six crosses, progenies within the individual crosses and different generations within each. Considering the differences in the three susceptible parents and the locational and seasonal differences under which the three generations were grown, it is felt a comprehensive type of resistance has been found.

Sunflower rust, caused by *Puccinia helianthi* Schw., is one of the major hazards in sunflower seed production in Manitoba. The area planted to the crop declined rapidly from 60,000 acres in 1949 to 3,500 acres in 1952, largely because of the losses due to rust on the susceptible Advance hybrid, the variety which is grown on almost the entire acreage. In recent years resistance to rust has been discovered in a number of sunflower introductions at the Morden Station (2). This paper reports on the inheritance, under field conditions, of the resistance of one line, 953-102-1-1-22, selected from one of these introductions.

MATERIALS AND METHODS

Seed resulting from open pollination at Renner, Texas, of an F_1 plant of the natural cross California Oilseed by Texas Wild Annual was grown at Morden in 1950. A single plant from this seed showed light rust infection. Its progeny from open pollination contained a large plant in the 1951 season on which only two small rust pustules were found when adjacent susceptible plants carried up to 100 per cent infection. Only open pollinated seed was obtained. In the winter of 1951-1952 the progeny of this plant was grown in Chile and also in the greenhouses at Morden and Ottawa. In all, 58 plants were self-pollinated and their progenies grown at Morden in 1952.

One of the 58 selfed progenies designated 953-102-1-1-22 had 15 plants. On 4 of these no rust was found; on 10 others it was difficult to find, only a single pustule being located on several; and on the last plant one or two pustules were found on each leaf. Severe infections occurred on nearby

[1] Contribution from Division of Forage Crops, Experimental Farms Service, Canada Department of Agriculture, Ottawa, Canada.
[2] Agrostologist, Experimental Station, Morden, Manitoba.
[3] Ing° Agronomist, Agricultural Experiment Station of La Molina, Ministry of Agriculture of Peru.

TABLE 1.—PEDIGREE OF CROSSES BETWEEN RUST RESISTANT AND RUST SUSCEPTIBLE SUNFLOWER LINES

Cross number	Female parent (rust susceptible)	Male parent (rust resistant)
67	S-37-388	953-102-1-1-22-4
68	Sunrise	953-102-1-1-22-1
69	Sunrise	953-102-1-1-22-4
75	S-37-388	953-102-1-1-22-5
77	9-2-5-2	953-102-1-1-22-10
78	9-1-3-3	953-102-1-1-22-3

susceptible sunflowers. This 953-102-1-1-22 progeny was also the most desirable in other agronomic characters so that it was chosen for crossing with rust susceptible but otherwise desirable lines.

In the summer of 1952 the crosses listed in Table 1 were made. The S-37-388 line is a selection of high combining ability from the highly heterogeneous Mennonite variety. It is consistently the most rust susceptible line grown on the Morden Station. It frequently bears infections up to 100 per cent and is occasionally destroyed by rust before flowering is completed. Sunrise, another of the parents listed in Table 1, is a uniform variety resulting from combining inbred selections out of a Russian introduction. It is not as severely attacked by rust in the field as S-37-388 but will have infections up to 80 per cent in a heavy epidemic. The 9-2-5-2 and 9-1-3-3 lines are inbred selections from a single plant of the Mennonite variety. They are susceptible to rust but usually show much less infection than either S-37-388 or Sunrise.

All crosses listed in Table 1 were between individual plants. The male parents were single plants within the 953-102-1-1-22 progeny. Note also from Table 1 that crosses 67 and 69 had the same rust resistant parent plant as a male on the two susceptible types, S-37-388 and Sunrise.

The F_1 plants of the crosses were grown in Chile in the winter of 1952-1953 and self-pollinated. The F_2 populations, from separate F_1 plants, were produced in the field at Morden in 1953. Self seed of resistant F_2 plants was sent to La Molina, Peru, to produce an F_3 generation in the field during the winter of 1953-1954. In 1954, at Morden, F_4 progenies were grown from resistant plants of the La Molina plots. In addition, as a check on the segregation ratios of previous seasons, a small number of F_2 and F_3 progenies was grown from crosses 67, 69 and 75 and also a few plants from F_1 remnant seed.

All material at Morden was grown in 15-plant rows. Spacing was 3 feet between rows and $1\frac{1}{2}$ feet between plants. An extra plant of the highly susceptible S-37-388 was grown at the end of each row to aid in developing inoculum. Check rows of the susceptible and resistant parents

of each cross were included. The F_2 progenies ranged in number from 51 to 111 plants, depending on the amount of seed available, from each F_1 plant. The F_3 progenies consisted of two rows each and F_4 of one row. Plant stand obtained in 1954 was variable so that progenies ranged from only two plants to full stand.

At La Molina, 25 seeds of each F_3 progeny were planted in a 5-metre row. Stands obtained also varied ranging from 1 to 21 plants for the separate progenies. A susceptible check variety was grown in every tenth row.

At Morden, in 1954, the spreader plants of S-37-388 were inoculated with a collection of uredospores obtained in the field the previous season and stored all winter in a household refrigerator. Rust readings in per cent were made in the late summer of 1953 and 1954 using the rust estimating scale of Peterson *et al.* (1) as a guide. Plants with infections of 1 per cent or less were classified as resistant and 2 per cent or over as susceptible. Very few plants had infections near the extremes of these two classes. Most resistant plants had either no rust or only one or two pustules per leaf. Susceptible plants, with few exceptions, had minimum infections of 5 per cent and the great majority 30 to 60 per cent.

At La Molina, the seedlings were inoculated with a local field collection of uredospores. Decision between resistant and susceptible plants was based on reaction type pustule as observed in the late seedling or early pre-bloom stage, and checked again just before maturity.

There was good agreement between the results of the different seasons and at the two locations. Accordingly the data of the various generations and progenies are presented without regard to the location of their origin. It will be recalled, however, that the F_3 data are largely from La Molina while all F_2 and F_4 results are from Morden.

EXPERIMENTAL RESULTS

Parent Material and F_1 Plants

Rust was not present in Chile in 1952-1953. Therefore no records were obtained for the F_1 plants grown there. The F_1 plants grown at Morden in 1954 were resistant showing infections of 1 per cent or less. The 953-102-1-1-22 parent was also resistant. Susceptible check plants of the S-37-388 and other parents showed infections of 20 per cent and more. These results indicate dominance of resistant character.

Segregation and Chi-square Goodness of Fit Tests

A summary of the total populations of the F_2 generation and of the segregating progenies of the F_3 and F_4 generations for the six crosses is shown in Table 2 together with Chi-square and probability values for goodness of fit to a 3 : 1 ratio of resistant to susceptible plants.

Examination of the data in Table 2 shows a relatively good fit to the 3 :1 ratio. In the total study 2789 resistant and 953 susceptible plants were observed. The Chi-square value for the 3 : 1 ratio is 0.4365 corresponding to a probability between 0.50 and 0.70.

Considering the total populations of individual crosses it is seen that those from crosses 67, 68 and 69 show excellent fits to the 3 : 1 ratio with

probability values between 0.50 and 0.90. The ratio of 1330 resistant plants to 440 susceptible plants in cross 67 gives the closest fit with a high probability of 0.80 to 0.90. The segregations of the other crosses 75, 77 and 78 show somewhat poorer fits but their probability values are still well above the 5 per cent level.

Examining the separate generations within each cross in Table 2 shows that the Chi-squares obtained all correspond to probability values above the 5 per cent level. For several, the probability is somewhat low, especially for the F_2 of crosses 75 and 78. However, it is noteworthy that all crosses except 77 show at least one generation which fits the 3 : 1 ratio well as indicated by probability values of 0.50 or larger, supporting the view that the

TABLE 2.—CHI-SQUARE AND PROBABILITY VALUES FOR GOODNESS OF FIT TO A 3 : 1 RATIO OF RUST RESISTANT AND SUSCEPTIBLE PLANTS IN F_2 AND SEGREGATING F_3 AND F_4 PROGENIES FROM SIX CROSSES

Cross number	Generation	Number of progenies	Resistant plants	Susceptible plants	X^2	P value
67	F_2	7	313	105	0.0003	0.98-0.99
67	F_3	51	637	189	1.9774	0.10-0.20
67	F_4	62	380	146	2.1318	0.10-0.20
67	Totals		1330	440	0.0188	0.80-0.90
68	F_2	2	119	38	0.0531	0.80-0.90
68	F_3	7	40	12	0.1026	0.70-0.80
68	Totals		159	50	0.1292	0.70-0.80
69	F_2	4	262	85	0.0047	0.90-0.95
69	F_3	21	137	54	1.0908	0.20-0.30
69	F_4	9	54	21	0.3600	0.50-0.70
69	Totals		453	160	0.3964	0.50-0.70
75	F_2	1	38	21	3.4153	0.05-0.10
75	F_3	11	131	44	0.0019	0.95-0.98
75	F_4	5	41	18	0.9548	0.30-0.50
75	Totals		210	83	1.7300	0.20-0.30
77	F_2	3	140	40	0.7407	0.30-0.50
77	F_3	13	130	54	1.8551	0.10-0.20
77	F_4	18	173	69	1.5922	0.20-0.30
77	Totals		443	163	1.1639	0.20-0.30
78	F_2	2	117	26	3.5457	0.05-0.10
78	F_3	4	35	10	0.1852	0.50-0.70
78	F_4	5	42	21	2.3333	0.10-0.20
78	Totals		195	57	0.7619	0.30-0.50
Totals all crosses			2789	953	0.4365	0.50-0.70

diversions from the 3 : 1 ratio are due to chance alone. Even in cross 77 the F_2 generation shows a satisfactory fit with a probability value between 0.30 and 0.50.

The F_3 progenies which descended from resistant F_2 plants were separated into two classes, namely those segregating and not segregating. One hundred and seven progenies showed segregation and 84 did not. As many progenies were small, due to poor stands, segregation would not have been observed in several in which it would actually have existed. Consequently, the data were reclassified using only those progenies with eight plants or more. On this basis, 92 of the F_3 progenies from resistant plants segregated and 54 did not. The Chi-square test for fit to a 2 : 1 ratio gave a value of 0.8767 corresponding to a probability between 0.30 and 0.50 thus showing a good fit.

Homogeneity of Data

A Chi-square test for homogeneity of the total populations in the six crosses gave a value of 3.6593 corresponding to a probability between 0.50 and 0.70 thus showing good homogeneity.

The homogeneity of the data of the different generations within each cross was also tested by Chi-square. The following probability values were obtained: *cross 67*: 0.10-0.20; *cross 68*: 0.80-0.90; *cross 69*: 0.50-0.70; *cross 75*: 0.20-0.30; *cross 77*; 0.20-0.30 and *cross 78*: 0.05-0.10. These values are all above the 5 per cent level indicating satisfactory homogeneity of the data from the different generations. Except for crosses 68 and 69 the values are not high. However, if it is recalled that the major portion of the F_3 data was obtained in Peru and that the method of deciding between resistant and susceptible plants was based on pustule type as contrasted with per cent infection at Morden, then the homogeneity indicated is good. Also the fact that F_2 and F_4 data were largely obtained in separate seasons might prevent high homogeneity.

In Table 3 the segregation of each F_2 progeny and of the total populations descending from them are shown for the separate crosses. The Chi-square values and corresponding probability are given for testing the homogeneity of each generation within the various crosses. All the probability values are well above the 5 per cent level thus showing good homogeneity for the data. In 10 of the 14 instances the probability is above 0.50 and in seven above 0.70. The F_2 of crosses 67 and 78 and the F_3 of cross 77 have given the relatively low values of 0.20 and 0.30 but even these are sufficiently high to indicate satisfactory homogeneity of the different progenies.

DISCUSSION

The results lead to the conclusion that the rust resistant character, assumed to have originated in the wild annual sunflower of Texas, is dominant and inherited on a monofactorial basis. The consistency of the segregating populations in conforming to the 3 : 1 ratio is striking, considering that three susceptible parents, differing markedly in their degree of field infection, were used in the six crosses; that the data were obtained in three seasons and from two widely separated countries and that the methods of distinguishing resistant and susceptible plants were different at the two

TABLE 3.—HOMOGENEITY CHI-SQUARE AND PROBABILITY VALUES FOR INDIVIDUAL F_2 PROGENIES AND FOR TOTAL POPULATIONS OF SEGREGATING PROGENIES IN F_3 AND F_4 GENERATIONS DESCENDING FROM EACH F_2 IN FIVE CROSSES BETWEEN RUST RESISTANT AND SUSCEPTIBLE LINES

	F_2		F_3		F_4	
	Resistant	Susceptible	Resistant	Susceptible	Resistant	Susceptible
Cross No. 67						
	47	19	95	29	116	37
	58	15	58	15	9	3
	39	23	79	26	18	6
	41	10	65	13	4	3
	48	14	250	78	193	77
	40	11	67	19	36	18
	40	13	23	9	4	2
Totals	313	105	637	189	380	146
X^2	7.4000		2.8085		2.9156	
P value	0.20-0.30		0.80-0.90		0.80-0.90	
Cross No. 68						
	55	19	23	7	—	—
	64	19	17	5	—	—
Totals	119	38	40	12		
X^2	0.1653		0.0027			
P value	0.50-0.70		0.95-0.98			
Cross No. 69						
	49	11	19	10	35	12
	85	26	37	13	17	8
	59	24	28	12	—	—
	69	24	53	19	2	1
Totals	262	85	137	54	54	21
X^2	2.2635		0.9333		0.3738	
P value	0.50-0.70		0.80-0.90		0.80-0.90	
Cross No. 77						
	48	16	34	10	76	35
	44	14	96	44	94	34
	48	10	—	—	—	—
Totals	140	40	130	54	173	69
X^2	1.2413		1.2224		0.9170	
P value	0.50-0.70		0.20-0.30		0.30-0.50	
Cross No. 78						
	41	12	12	4	24	13
	76	14	23	6	18	8
Totals	117	26	35	10	42	21
X^2	1.1263		0.1109		0.1311	
P value	0.20-0.30		0.70-0.80		0.70-0.80	

locations. This behaviour suggests that a comprehensive type of resistance is involved which will be of value in the breeding programs of other countries besides Canada. Early work with it in Argentina is promising.

The Canadian sunflower breeding program stands to benefit materially by the simple inheritance of this rust resistant character. Almost the entire Canadian acreage is now planted to Advance hybrid, which is highly desirable in most agronomic characters except for its rust susceptibility. It is produced in crossing blocks by natural cross pollination of the S-37-388 inbred line and the Sunrise variety. Because of its greater self-sterility and lower pollen production, the percentage of natural crossing is greater in S-37-388 than in Sunrise. Consequently, only the "hybrid" seed from S-37-388 is harvested for seed purposes. This seed is a composite mixture of cross-fertilized, self and sib seed of S-37-388.

The simple transfer of the rust resistance from the 953-102-1-1-22 line to the parents of Advance by backcrossing is anticipated. This will correct the major defect of this hybrid. With dominance of resistance it should be necessary to have this character in the S-37-388 parent only. Such a program is now well under way. Equally valuable is the feasibility of using the same simple backcrossing procedure to place rust resistance in several other promising but susceptible inbred lines now in the Canadian breeding program.

ACKNOWLEDGEMENTS

The authors express their appreciation to Mario Astorga C., Ministerio de Agricultura, Santiago, Chile, for production of the F_1 plants in his country, and to A. F. Swanson, Institute of Inter-American Affairs, Lima, Peru, for completing the arrangements at La Molina. Helpful suggestions given during the study by W. E. Sackston, Laboratory of Plant Pathology, Canada Department of Agriculture, Winnipeg, Manitoba, are gratefully acknowledged.

REFERENCES

1. Peterson, R. F., A. B. Campbell, and A. E. Hannah. A diagrammatic scale for estimating rust intensity on leaves and stems of cereals. Can. J. Res. *C*, 26 : 496-500. 1948.
2. Putt, Eric D., and W. E. Sackston. Rust resistance in sunflowers (*Helianthus annuus* L.). Nature 176 : 77. 1955.

CROP SEQUENCE STUDIES ON IRRIGATED LAND IN SOUTHERN ALBERTA[1]

S. Dubetz, G. C. Russell and K. W. Hill

Canada Department of Agriculture, Lethbridge, Alberta

[Received for publication July 29, 1955]

ABSTRACT

Yield results for four seasons in a crop sequence experiment on irrigated land are reported. Seven different cash crops (canning peas, canning corn, potatoes, barley, soft spring wheat, sugar beets and field beans) were included and each crop was grown after itself, after summer-fallow, and after the other six crops. Field beans were found to be the best preceding crop; potatoes and canning peas, respectively, were next in order of merit. Barley and sugar beets were the least effective preceding crops. The subsequent volunteer growth of barley added to the problem of sequence management. There were no significant differences in yields of wheat and canning corn. The greatest reduction in yield in this sequence test was obtained when potatoes were grown after potatoes. Plots which previously had grown canning peas were the most heavily infested with weeds, while the intertilled crops—sugar beets, corn, and beans—were the least weedy. Summer-fallowing irrigated land was not justified on the basis of comparative yearly gross returns.

INTRODUCTION

Well-planned crop rotations are necessary for maximum crop production. Under intensive irrigation farming, the choice of a great variety of crops, along with the use of manures and fertilizers, requires exacting care in the setting up of satisfactory rotations. The beneficial use of legumes in rotations has long been recognized, and recent experiments (3, 4, 9) have established their value more definitely. The effects of barnyard manure, commercial fertilizers and timely application of water also warrant special consideration in planning rotations for irrigated land.

The sequence of cropping often has a marked effect on the yield of certain crops (5, 6, 8) and, therefore, it is an important phase of rotation planning. In southern Alberta, there was a need for information on the effect of cropping sequence alone, irrespective of other rotational factors. The results of an experiment set up to study the effects on the following crop of some of the important crops grown in southern Alberta are presented in this report.

PROCEDURE

In 1947, seven crops—canning peas, canning corn, potatoes, barley, soft spring wheat, sugar beets, and field beans—were grown in adjacent strips at four locations at the Lethbridge Experimental Farm. The crop varieties recommended for southern Alberta were used throughout the test. In 1948, these crops were grown transversely across the preceding strips and a summer-fallow strip, allowing each crop to be grown after itself, after fallow, and after the other six crops. The following year, the crops were grown crosswise to the 1948 plots, thus providing two years of sequence

[1] Contribution from the Field Husbandry Division, Experimental Farms Service.

crops, and completing one cycle. All of the plots were seeded to oats in 1950, after which the experiment was repeated until two sequence cycles were completed.

To obtain maximum crop yields and yet maintain relatively uniform fertility, ammonium phosphate (11-48-0) fertilizer, at the rate of 100 lb. per acre, was applied each spring over the whole area of each location prior to seeding. No further fertilizer applications were made.

The size of each plot was 19 by 40 feet, and appropriate samples of each crop were harvested. In the calculation of the data for the analysis of variance, the locations were treated as replicates. All of the crops were irrigated with a perforated-pipe sprinkler system.

RESULTS AND DISCUSSION

The 4-year (1948, 1949, 1952, and 1953) average yields of the sequence crops and the comparative gross returns per year, following each preceding crop, appear in Table 1.

Field beans were the outstanding preceding crop in this test, on the basis of yields of succeeding crops and gross returns per acre. Barley, beans, peas, sugar beets, and wheat yielded the highest after beans. The yields of barley, beans, peas, and sugar beets were significantly higher following beans than the yields obtained following sugar beets, corn, wheat, and barley. The beneficial effect of beans as a preceding crop possibly is due to the additional nitrogen made available to the subsequent crops by this annual legume. This is in agreement with the findings of Guttay and Cook (2), who reported that additional nitrogen was not so beneficial in a sequence in which sugar beets followed beans as in other crop sequences. The greatest average gross returns per acre per year (Table 1) were obtained from plots that previously had grown beans. The 4-year average yield of 1694 lb. of beans per acre would make this a profitable crop to grow in southern Alberta.

Potatoes ranked second to field beans as a preceding crop. This may be partially attributed to the good physical structure and tilth of the soil following potatoes. However, yields of potatoes were poorest when grown after themselves, the yields being significantly lower than those obtained following all the other crops, except barley. Odland (7) reports potatoes did most poorly when following potatoes, rutabagas, or millet. The highest yield of potatoes (Table 1), excluding that after fallow, was obtained after corn, but this yield was not significantly higher than the yields following peas, wheat, beans, and sugar beets.

There were no significant differences in the yields of barley, peas, potatoes, and sugar beets when grown after beans, potatoes, or canning peas. The superiority of beans and potatoes as preceding crops for sugar beets was observed by Carlson (1). He attributed it to the early rapid absorption of nutrients by the root crop when grown after beans and potatoes. Although canning peas also are an annual legume, they were not as effective a preceding crop as were beans. It was difficult to control weeds in the pea plots and, as a result, these plots contained the most weeds the following spring. The competition with weeds for plant nutrients

TABLE 1.—FOUR-YEAR AVERAGE (1948-1949, 1952-1953) CROP YIELDS[1] AND CALCULATED GROSS RETURNS FOLLOWING DIFFERENT PRECEDING CROPS AND SUMMER-FALLOW IN A CROP SEQUENCE TEST, LETHBRIDGE, ALBERTA

Crop	Preceding crop							Grown after fallow[2]	L.S.D.[3]
	Barley	Beans	Corn	Peas	Potatoes	S. beets	Wheat		
Barley—bu. per acre	67.8	84.5	72.4	75.5	76.6	73.4	69.6	74.0	9.8
Gross returns at 90c. per bu.	$ 61.02	76.05	65.16	67.95	68.94	66.06	62.64	66.60	
Beans—lb. per acre	1564	2012	1663	1663	1863	1553	1540	1856	262
Gross returns at 8c. per lb.	$125.12	160.96	133.04	133.04	149.04	124.24	123.20	148.48	
Canning corn—tons per acre	6.68	7.10	6.98	7.38	7.38	6.72	6.45	7.14	N.S.
Gross returns at $20 per ton	$133.60	142.00	139.60	147.60	147.60	134.40	129.00	142.80	
Canning peas—tons per acre	1.71	2.09	1.83	1.89	1.91	1.72	1.71	1.86	0.12
Gross returns at $95 per ton	$162.45	198.55	173.85	179.55	181.45	163.40	162.45	176.70	
Potatoes—tons per acre	7.54	8.65	9.26	8.76	6.50	8.16	8.72	9.47	1.27
Gross returns at $25 per ton	$188.50	216.25	231.50	219.00	162.50	204.00	218.00	236.75	
Sugar beets—tons per acre	10.66	12.97	11.62	12.26	12.58	10.67	10.98	16.12	1.32
Gross returns at $14 per ton	$149.24	181.58	162.68	171.64	176.12	149.38	153.72	225.68	
Wheat—bu. per acre	47.4	53.2	49.6	48.4	51.1	46.8	50.0	52.8	N.S.
Gross returns at $1.60 per bu.	$ 75.84	85.12	79.36	77.44	81.76	74.88	80.00	84.48	
Average gross returns per acre per year	$127.97	151.50	140.74	142.32	138.20	130.91	132.72	77.25	

[1] Data are based on means of yields from replicates at four locations.
[2] Two-year averages only.
[3] L.S.D. does not refer to results after fallow.

may be the reason for the higher yields of some crops following potatoes and beans as compared with those following peas.

Because sugar beets occupy a large acreage in southern Alberta as compared with other irrigated cash crops, they should receive special consideration in a rotation sequence. It is a common practice to grow them after canning peas or potatoes. The results of this experiment show that this is a good practice. The performance of this root crop was poorest when grown after itself or barley.

There were no significant differences in yields of canning corn and wheat following the various other crops. Because of this lack of response to the various sequence treatments, corn and wheat apparently could be grown satisfactorily in any rotation sequence, and thus add flexibility to a rotation. From a management standpoint, because of better weed control in intertilled crops, canning corn could be favoured over wheat as a preceding crop.

Barley was the least effective preceding crop. The tendency of the crop to shatter, with the subsequent volunteer growth, is an undesirable characteristic of barley in rotation management.

Crop yields after summer-fallow are available for only two years. From Table 1, it is apparent that the comparative cash returns from fallowing are not encouraging. The average annual gross returns from crops grown after summer-fallow were $77.00 per acre, as compared with $151.00 from crops grown after beans.

REFERENCES

1. Carlson, W. E. The distribution of mineral elements in the sugar beet as influenced by different preceding crops. Soil Sci. 54 : 425-437. 1942.
2. Guttay, J. R., and R. L. Cook. The effect of crop sequence and early summer temperature on the response of sugar beets to supplementary nitrogen. Mich. Agr. Expt. Quart. Bull. 35 : 482-488. 1953.
3. Hansen, Dan, and A. H. Post. Irrigated crop rotations. Mont. Agr. Expt. Sta. Bull. 414. 1943.
4. Kiesselbach, T. A., and W. E. Lynes. Crop rotation experiments. Nebr. Agr. Expt. Sta. Bull. 416. 1952.
5. Leighty, Clyde E. Crop rotation. Soils and men. Yearbook of Agriculture, U.S.D.A., pp. 406-430. 1938.
6. Lill, J. G. A study of the crop-sequence and fertilization factors in crop production. J. Am. Soc. Agron. 38 : 795-803. 1946.
7. Odland, T. E., *et al.* The influence of crop plants on those which follow. V. R.I. Agr. Expt. Sta. Bull. 309. 1950.
8. Ripley, P. O. The influence of crops upon those which follow. Sci. Agr. 21 : 522-583. 1941.
9. Wahhab, A., and Muhammad Taj. The role of legumes in improving soil fertility. II. Effect of the crop residues left after harvest in the soil on the soil fertility. Pakistan J. Sci. Res. 6 : 48-51. 1954.

STUDIES ON CONTROL OF CATERPILLARS ON CABBAGE IN THE OTTAWA VALLEY, 1953-1954[1]

D. G. Harcourt and L. M. Cass[2]

Vegetable Insect Section, Entomology Laboratory, Ottawa, Canada

[Received for publication August 21, 1955]

ABSTRACT

Late cabbage grown near Ottawa, Ontario, were treated on July 20 and August 2, 15, and 30, 1953 and 1954, with foliage applications of insecticides applied as sprays or dusts to protect the plants from the imported cabbageworm, the diamondback moth, and the cabbage looper. Twenty per cent emulsifiable concentrate of endrin at 0·25 lb. of toxicant per acre, 50 per cent wettable DDT powder at 1·0 lb., and 3 per cent DDT dust at 1·0 lb., all gave excellent control; 4 per cent malathion dust at 1·5 lb. and 20 per cent emulsifiable concentrate of dieldrin at 0·25 lb. gave good control; 25 per cent wettable malathion powder at 1·5 lb. and 20 per cent emulsifiable concentrate of isodrin at 0·25 lb. gave only fair control. Comparison of present and past effectiveness of DDT did not suggest any build-up of resistance to this material by any of the species.

INTRODUCTION

Cabbage and related crops are attacked each season in most provinces of Canada by caterpillars of three species, namely, the imported cabbageworm, *Pieris rapæ* (L.), the diamondback moth, *Plutella maculipennis* (Curt.), and the cabbage looper, *Trichoplusia ni* (Hbn.). The three species damage cabbage and cauliflower chiefly, but they also feed on the foliage of turnip, radish, brussels sprouts, broccoli, and a wide variety of weeds and ornamental plants of the family Cruciferæ. Because of their widespread distribution and the value of the crops attacked, they constitute one of the most important groups of insects attacking vegetable crops in Canada.

Because of the excellent control afforded by the chlorinated hydrocarbon insecticides, these insects have been given little attention by entomologists in recent years. Experiments at Ottawa from 1947 to 1950 showed that almost complete control of caterpillars attacking late cabbage can be obtained with four applications of 3 per cent DDT dust, on about

Table 1.—Relative abundance of caterpillars attacking late cabbage, Merivale, Ont., 1953

Date	Total for 25 plants	Percentage of total		
		Pieris rapae	*Plutella maculipennis*	*Trichoplusia ni*
July 17	305	67·2	32·8	0·0
July 29	282	56·4	42·6	1·0
August 12	301	21·9	73·8	4·3
August 25	455	42·4	54·5	3·1
September 9	790	13·2	84·8	2·0
Mean	—	34·1	63·7	2·2

[1] Contribution No. 3347, Entomology Division, Science Service, Department of Agriculture, Ottawa, Canada.

[2] Associate Entomologist and Technician.

July 20 and August 2, 15, and 30 (6). However, in 1951, field strains of the imported cabbageworm resistant to DDT, TDE, and methoxychlor were found to have developed in Wisconsin (7). Evidence of strains of the cabbage looper resistant to DDT were observed in New York during 1952 (2, 4); resistance to DDT by strains of the diamondback moth was reported the following year from Java (5). Hence, the effectiveness of DDT was revaluated. This paper is a report on experiments at Ottawa, 1953-1954, on re-assessing the effectiveness of DDT for control of caterpillars on cabbage, and on comparing its effectiveness with those of several new insecticides.

METHODS AND MATERIALS

Materials and Application

Table 2 shows the insecticides and the concentrations at which they were tested. The dusts were applied with rotary hand dusters at average rates of 30 to 35 lb. per acre of the diluted dust. The wettable powders and emulsifiable concentrates were applied with knapsack sprayers at average rates of 80 to 100 gal. per acre of the diluted spray. The schedule of application was that followed in the 1947-1950 experiments, thus providing a ready comparison of the present and past effectiveness of DDT.

Location, Arrangement, and Size of Plots

The experimental plots were in growers' fields, at Merivale, Ontario, in 1953, and at Aylmer East, Quebec, in 1953 and 1954. The plots, which averaged one-fiftieth of an acre in size, were arranged in randomized blocks with six replications. The experimental areas were as follows: Merivale,

TABLE 2.—CONTROL OF CATERPILLARS ON LATE CABBAGE WITH FOUR BI-WEEKLY APPLICATIONS OF VARIOUS MATERIALS, MERIVALE, ONT., 1953

Material	Formulation	Toxicant per acre, lb.	Cabbage plants		Percentage control
			Number examined	Percentage Grade 2[1]	
Endrin[2]	20% em. conc.	0·25	305	2·0	97·9
DDT[3]	3% dust	1·00	306	2·0	97·9
DDT[3]	50% w. p.	1·00	308	2·9	97·0
Malathion[4]	4% dust	1·50	293	13·3	86·1
Isodrin[2]	20% em. conc.	0·25	285	13·7	85·7
Malathion[4]	25% w. p.	1·50	314	28·9	69·8
Check, untreated	—	—	264	95·8	—
Difference required for significance at 5% level				5·2	
at 1% level				7·6	

[1] Five or more leaves skeletonized on September 15.
[2] Shell Chemical Company of Canada, Toronto 1, Ont.; 2 lb. of toxicant per gal.
[3] Green Cross Insecticides, Montreal 22, Que.
[4] North American Cyanamid Co., Toronto 1, Ont.

$\frac{3}{5}$ acre; Aylmer East, $\frac{4}{5}$ acre in 1953 and 1 acre in 1954. The variety of cabbage in all three experiments was Penn State Ballhead.

Criteria of Effectiveness

Effectiveness was based on feeding injury to the foliage shortly before harvest, viz., 2 to 4 weeks after the final application of insecticides, at Merivale and Aylmer East on September 15 and 17 respectively in 1953, and on September 30 in 1954. The foliage injury records were taken independently by two observers and the results averaged. Because of the possibility of insecticidal drift, not all of the plants in the experimental plots were graded; about one-third of the plants in each plot, the outside rows and a 3-foot strip at the end of each row, were left as buffers. The cabbage was graded according to damage to the heads and leaves as follows: *Grade 1*, Up to four leaves skeletonized; *Grade 2*, Five or more leaves skeletonized. The latter category denoted sufficient injury to reduce or destroy the market value of the crop. A skeletonized leaf was regarded as one in which more than one-sixth of the leaf surface had been removed by feeding.

Differences between the treatments were assessed by the multiple range test of Tukey*.

Population Records

To determine the relative abundance of the species attacking the plants, counts of the various species were made each year in the check plots. That for the field at Merivale in 1953 is typical. Table 1 shows that the diamondback moth was the most abundant species during the season; the imported cabbageworm was most abundant during July; the diamondback moth, during August and September. The cabbage looper did not form a significant portion of the species complex.

RESULTS AND DISCUSSION

A large infestation of caterpillars was present in each of the experimental fields each year, 92 to 96 per cent of the check plants having feeding injury classified as *Grade 2*. Data on the effectiveness of the materials are summarized in Tables 2 and 3. Endrin and both formulations of DDT consistently gave excellent control of the caterpillars, significantly better control than the remaining treatments. As a dust, malathion gave good, but not outstanding, control in all three experiments. As a wettable powder, malathion gave good control at Aylmer East in 1953, fair control in the other two experiments. Isodrin gave good protection at both sites in 1953, fair protection in 1954. Dieldrin gave good, but not outstanding, control in the only season in which it was tested.

A comparison of the present and past effectiveness of DDT in the Ottawa Valley does not suggest any build-up of resistance to this material by caterpillars on cabbage. The control afforded by four applications of 3 per cent DDT dust in the 1953-1954 experiments compares favourably with that obtained in 1947 to 1950, when the schedules of application and grades of feeding injury to the foliage were essentially the same. The percentages of control ranged from 96 to 100 in 1947-1950 and were 99 and

---

* Tukey, J. W. The problem of multiple comparisons. *Unpublished notes*, Princeton University (*processed*).

TABLE 3.—CONTROL OF CATERPILLARS ON LATE CABBAGE WITH FOUR APPLICATIONS OF VARIOUS MATERIALS, AYLMER EAST, QUE.

Material	Formulation	Cabbage plants				Percentage control	
		Number examined		Percentage Grade 2[1]			
		1953	1954	1953	1954	1953	1954
Endrin	20% em. conc.	661	561	0·6	1·2	99·4	98·7
DDT	3% dust	666	584	0·8	1·5	99·2	98·4
DDT	50% w. p.	663	593	2·4	6·4	97·5	93·1
Malathion	4% dust	679	550	7·7	15·8	92·0	82·8
Dieldrin[2]	20% em. conc.	—	623	—	18·5	—	79·9
Malathion	25% w. p.	673	585	11·1	26·2	88·5	71·6
Isodrin	20% em. conc.	674	619	12·0	27·6	87·6	70·0
Check, untreated	—	660	573	96·7	92·1		
Difference required for significance at 5% level				2·3	3·5		
at 1% level				3·3	5·1		

[1] Five or more leaves skeletonized, September 17, 1953, and September 30, 1954.
[2] Shell Chemical Company of Canada, containing 2 lb. of technical dieldrin per gal.; applied at 0·25 lb. of toxicant per acre.

98 in 1953 and 1954. Similar comparisons of present and past effectiveness of DDT in western New York (4) have shown that the effectiveness of this material is steadily declining. Its failure to give good control in New York was apparently due to development of resistant strains of the cabbage looper. The latter is rarely of importance at Ottawa (3) and did not form a significant portion of the species complex in any of the experimental fields.

As a result of these and earlier experiments (6), a four-application schedule employing DDT has been recommended (8) for control of caterpillars attacking cabbage in eastern Ontario: July 20, August 4 and 19, and September 3. With little modification this schedule should be applicable to south-central Ontario as well; records of field populations near Bradford, 1954, showed that the species were present in the same ratio as at Ottawa.

Endrin, although at present slightly less economical than DDT, should be an adequate alternative material. It may be expected to give almost equal control of non-resistant strains of caterpillars and superior results with resistant strains. In Wisconsin (1) endrin has shown considerable promise in the control of field populations of caterpillars that are resistant to DDT, TDE, and methoxychlor.

These experiments were designed also to compare the effectiveness of the several insecticides in the control of the cabbage aphid, *Brevicoryne brassicæ* (L.), but since no infestation of this insect developed in the experimental fields no conclusions can be drawn. Four per cent malathion dust, one of the materials now recommended for control of the cabbage aphid in Ontario (8), may be expected to give satisfactory protection against the imported cabbageworm and the diamondback moth as well, providing not less than four applications are made. Malathion wettable powder cannot be recommended for combined control of caterpillars and aphids on the basis of the present experiments.

REFERENCES

1. Chapman, R. K. Vegetable insects. *In* Insect control in 1955, ed. by E. H. Fisher, pp. 12-18. Univ. of Wisconsin Special Circular 34. 1955.
2. Chupp, C., and R. W. Leiby. The control of diseases and insects affecting vegetable crops. Cornell Ext. Bull. 206. 1953.
3. Harcourt, D. G., R. H. Backs, and L. M. Cass. Abundance and relative importance of caterpillars attacking cabbage in eastern Ontario. Can. Ent. 87: 400-406. 1955.
4. Hervey, G. E. R., and K. G. Swenson. Effectiveness of DDT for cabbage caterpillar control in western New York: 1944 and 1953. J. Econ. Ent. 47: 564-567. 1954.
5. Johnson, D. R. *Plutella maculipennis* resistance to DDT in Java. J. Econ. Ent. 46: 176. 1953.
6. Matthewman, W. G., D. G. Harcourt, and J. P. Perron. Timing of DDT applications for control of caterpillars on cabbage. Can. Ent. 84: 346-352. 1952.
7. McEwan, F. L., and R. K. Chapman. Imported cabbageworm resistance to insecticides. J. Econ. Ent. 45: 717-722. 1952.
8. Ontario Department of Agriculture and Canada Department of Agriculture. Protection calendar for vegetables. Ont. Dept. Agr., Fruit Branch, Toronto. 1955.

INHERITANCE OF WHITE PETAL IN GREEN SPROUTING BROCCOLI[1]

T. H. ANSTEY

Canada Department of Agriculture, Summerland, B.C.

[Received for publication July 29, 1955]

ABSTRACT

White petal (*W*), a natural mutation in green sprouting broccoli, is controlled by a single dominant factor. It is independent of, and epistatic to cream petal (*cr*). White petal is in the same linkage group as glossy foliage (*gl*), the estimated linkage intensity between the two factors being 25·32 per cent ± 2·69 per cent.

INTRODUCTION

The mode of inheritance of glossy foliage (*gl*) and cream petal (*cr*) in green sprouting broccoli has previously been described by Anstey and Moore (2). Each mutant characteristic was shown to be controlled by a single recessive factor. No other mutations have been described for *Brassica oleracea* L. var. *italica* Plenck, although considerable literature is available for other botanical varieties within the species. The normal flower colour in all species and varieties of *Brassica* as reported by Bailey (3) is light to bright yellow. Pearson (7) has described a single dominant factor controlling white flower (*W*) in *B. oleracea* horticultural variety Jersey kale. Cream petal in broccoli and white petal in kale, then, are the only flower colour mutations known to be reported in *B. oleracea*. Self-incompatibility genes have been reported in some broccoli lines (1, 8) and must be considered in a breeding program.

The present paper reports the mode of inheritance of white petal and its relationship to cream petal and glossy foliage in green sprouting broccoli.

MATERIALS AND METHODS

The normal petal colour of broccoli varies in intensity around sulphur yellow 1/2 (9) while the mutation here described produces a petal of pure white. Confusion with faded cream petals that change to white after exposure to intense sunlight must be avoided. Plants with white petal have normal viability and maturation. The symbol *W* is suggested for the factor controlling white petal in broccoli, conforming with Pearson's (7) symbolization. The mutation was found at the Western Washington Experiment Station[2] in 1951 in a commercial planting of the Medium variety from the Ferry-Morse Seed Company.

Cuttings were taken from selected plants in field culture for seed production in the greenhouse. In all cases the usual precautions were observed for the prevention of pollen contamination by using large glassine bags to cover whole racemes, or cigarette tubes to cover individual flowers. Selfings were made using buds, since self-incompatibility genes are known to be present in some broccoli lines.

Linkage calculations were made using the product method (4, 5) for F_2 and half backcross populations, and the direct method for the backcross

[1] Contribution No. 857 from the Division of Horticulture, Experimental Farms Service, Ottawa, Canada.
[2] Moore, John F. *Private communication.* Western Washington Expt. Station, Puyallup, Wash. 1951.

populations. The data from the three types of populations were then combined to obtain a single value using the weighted average method (6). This combined value was tested against each individual and group of populations using the Chi Square test.

EXPERIMENTAL RESULTS

White Petal

The original white-petalled plant was selfed and crossed with nine normal-petalled plants to produce nine F_1 populations. Only 4 or 5 plants were grown out in each of these populations. The classifications of populations resulting from these crosses are summarized in Table 1 from which it will be seen that the original plant was heterozygous for *W*. The selfed population, therefore, was equivalent to an F_2 population while the crossed populations were equivalent to backcrosses.

Suitable parental plants were selected from the field cultures and 31 F_2 and 57 backcross populations were grown out over a period of two years. The summarized data are presented in Table 2. Considering the populations individually, one of the 31 F_2 populations had $X^2 = 4{\cdot}8167$ $P = {\cdot}02 - {\cdot}05$ being deficient in yellow-petalled plants, while 4 of the 57 B/C populations gave X^2 values with $P =$ or $< {\cdot}05$. Three of these populations were deficient in yellow-petalled plants while the fourth was deficient in white-petalled plants. These deviations are no greater than would be expected with the number of populations studied. Both types of populations had satisfactory heterogeneity X^2s.

From these data, it may be concluded that white petal (*W*) is controlled by a single factor, dominant to normal yellow petal (*w*).

TABLE 1.—SUMMARY OF PHENOTYPIC CLASSIFICATION OF SELFED AND CROSSED POPULATIONS USING THE ORIGINAL WHITE-PETALLED BROCCOLI PLANT

Number of populations	Number in phenotype			X^2	P
	W	w	Total		
White selfed 1	3	1	4	0	1·00
White × normal 9	24	19	43	·5812	·25–·50
Heterogeneity				1·8188	·97–·99

TABLE 2.—SUMMARY OF PHENOTYPIC CLASSIFICATIONS FOR F_2 AND B/C POPULATIONS FROM A CROSS OF WHITE PETAL BY NORMAL (YELLOW) PETAL

Number of populations	Number in phenotype			X^2	P
	W	w	Total		
F_2 (*Ww* selfed and/or *Ww* × *Ww*) 31	1315	420	1735	·5397	·25–·50
Heterogeneity				31·1169	·25–·50
B/C (*Ww* × *ww* and/or reciprocal) 57	1609	1571	3180	·4305	·50–·75
Heterogeneity				56·3942	·25–·50

White Petal by Cream Petal

The cross white petal by cream petal was made with the original heterozygous white petal plant and produced 2 white petal plants and 3 yellow petal plants with the reciprocal producing 4 white and 1 yellow-petalled plants. From the 6 white-petalled plants, 5 F_2 and 4 backcross populations were produced by selfing and crossing with the cream-petalled parent respectively. The data obtained from these populations are presented in Table 3.

All individual F_2 populations give a satisfactory fit to a 12:3:1 ratio, although the total does not. Each population is deficient in white- and excess in yellow-petalled plants which, while not serious in any single population, becomes so in the total population. An examination of the backcross data, however, reveals that both individual and total populations give a satisfactory fit to a 2:1:1 ratio. The heterogeneity X^2 in each case

TABLE 3.—PHENOTYPIC CLASSIFICATION OF SELFED AND BACKCROSS POPULATIONS FROM A CROSS WHITE PETAL BY CREAM PETAL AND RECIPROCAL

Culture	Number in phenotype				X^2	P
	White	Yellow	Cream	Total		
F_2 *WwCrcr* selfed						
53029	43	19	4	66	4·404	·10–·20
034	27	9	3	39	·692	·70–·80
036	50	15	5	70	·235	·80–·90
038	61	25	6	92	3·724	·10–·20
040	62	23	5	90	2·741	·20–·30
Total	243	91	23	357	10·971	<·01
Heterogeneity					·825	·99
B/C *WwCrcr* × *wwcrcr*						
53030	54	22	20	96	1·583	·30–·50
032	22	15	16	53	1·566	·30–·50
035	39	16	14	69	1·290	·50–·70
037	50	25	19	94	1·149	·50–·70
Total	165	78	69	312	1·558	·70–·80
Heterogeneity					4·030	·30–·50

TABLE 4.—PHENOTYPE, F_2 AND BACKCROSS RATIOS RESULTING FROM GENOTYPES OF WHITE AND CREAM PETAL

Genotype	Phenotype	Ratios for	
		F_2	B/C
WWCrCr	white	1	0
WwCrCr	white	2	0
WWCrcr	white	2	0
WwCrcr	white	4	1
WWcrcr	white	1	0
Wwcrcr	white	2	1
wwCrCr	yellow	1	0
wwCrcr	yellow	2	1
wwcrcr	cream	1	1

is satisfactory. From these data it may be concluded that the factors controlling white and cream petals are independent, with *W* epistatic to *cr*. The various genotypes giving the phenotypes, F_2 and backcross ratios are set out in Table 4.

White Petal and Glossy Foliage

During a period of two years 11 F_2, 18 backcross and 7 half backcross populations were grown out from the cross glossy foliage yellow petal by normal foliage white petal and reciprocal.

A summary of the segregation for glossy foliage and flower colour in these populations is given in Table 5. The Chi Square tests would indicate that all are segregating as expected for each character, with the exception of the glossy segregation in the first group of half backcross populations. These are deficient in recessives. All heterogeneity tests are satisfactory.

Since white petal (*W*) was originally found in an otherwise normal plant and the glossy (*gl*) parent had yellow petals (*w*), all crosses were made in coupling. Glossy plants in the field grow slowly and therefore relatively fewer glossy plants bloom before frost than do normal plants. Since only coupling data were available, no correction for differential viability was possible. The product method used for the calculation of linkage overcomes this difficulty to some extent.

The Chi Square test for independence as presented in column (f) of Table 6 shows that all populations are uniformly segregating for *gl* and *W* with large Chi Square values having $P = < \cdot 001$. Linkage values were therefore calculated for each group of populations and combined giving a weighted average value of $25 \cdot 32$ per cent $\pm$ $2 \cdot 69$ per cent. This average value was then tested by Chi Square against the observed ratios, the summary of which is presented in columns (j) and (k) of Table 6. It will be noted, as expected after examining column (h), that Chi Square is somewhat high for the backcross and first half backcross groups. Heterogeneity in all cases is satisfactory.

TABLE 5.—SUMMARY OF CHI SQUARE TESTS FOR GLOSSY FOLIAGE AND WHITE PETAL SEGREGATIONS OF POPULATIONS USED IN LINKAGE STUDIES

Number of cultures	Number in phenotype		X^2	P	Number in phenotype		X^2	P
	Gl	*gl*			*W*	*w*		
F_2 *GlglWw* selfed 11	578	182	·3950	·50–·70	557	203	1·0970	·20–·30
Heterogeneity			10·6890	·30–·50			9·0863	·50–·70
B/C *GlglWw* × *glglww* and reciprocal 18	507	477	·8550	·30–·50	498	486	·1231	·70–·80
Heterogeneity			18·2634	·30–·50			18·0593	·30–·50
1/2 B/C *GlglWw* × *glglWw* and reciprocal 4	134	92	7·4385	·005–·01	177	49	1·1566	·20–·30
Heterogeneity			1·8876	·50–·70			1·6062	·50–·70
1/2 B/C *GlglWw* × *Glglww* and reciprocal 3	144	50	·0275	·80–·90	100	94	·1289	·70–·80
Heterogeneity			·4938	·70–·80			1·4280	·30–·50

TABLE 6.—SUMMARY OF INDEPENDENCE AND LINKAGE TESTS FOR POPULATIONS DERIVED FROM THE CROSS GLOSSY FOLIAGE YELLOW PETAL BY NORMAL FOLIAGE WHITE PETAL

Number of cultures	Number of phenotypes				Independence		Linkage	s.e.	Test at 25·32% linkage	
	GlW	*Glw*	*glW*	*glw*	X^2	P			X^2	P
(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h) %	(i) %	(j)	(k)
F_2 *GlglWw* selfed 11	475	103	82	100	99·8338	<·001	28·00	±1·98	4·9351	·10–·25
Heterogeneity					37·8476	·10–·25			33·9913	·25–·50
B/C *GlglWw* × *glglww* and reciprocal 18	397	110	101	376	322·0404	<·001	19·75	±1·26	8·8198	·025–·05
Heterogeneity					69·0789	·025–·05			68·9816	·10–·25
1/2 B/C *GlglWw* × *glglWw* and reciprocal 4	116	18	61	31	22·1075	<·001	34·20	±5·52	8·7014	·025–·05
Heterogeneity					7·9860	·50–·75			11·8648	·10–·25
1/2 B/C *GlglWw* × *Glglww* and reciprocal 3	90	54	10	40	27·4876	<·001	26·25	±5·61	1·4386	·50–·75
Heterogeneity					5·2659	·50–·75			5·7452	·25–·50

DISCUSSION

The description of white petal brings the number of mutations described in broccoli to three. Cream petal and glossy foliage are single factors, recessive, and independent. White petal, on the other hand, is also controlled by a single factor but dominant and linked with glossy foliage. In view of the fact that broccoli has 9 pairs of chromosomes it is remarkable that two of the first three mutations described should be in the same linkage group.

REFERENCES

1. Anstey, T. H. Self-incompatibility in green sprouting broccoli (*Brassica oleracea* L. var. *italica* Plenck.) I. Its occurrence and possible use in a breeding program. Can. J. Agr. Sci. 34: 59-64. 1954.
2. Anstey, T. H., and John F. Moore. Inheritance of glossy foliage and cream petals in green sprouting broccoli. J. Hered. 45: 39-41. 1954.
3. Bailey, L. H. Manual of cultivated plants. Rev. ed. Macmillan Co., New York. 1949.
4. Fisher, R. A., and Bhai Balmukand. The estimation of linkage from the offspring of selfed heterozygotes. J. Gen. 20: 79-92. 1928.
5. Immer, F. R. Formulae and tables for calculating linkage intensities. Genetics 15: 81-98. 1930.
6. Kramer, H. H., and C. R. Burnham. Methods of combining linkage intensity values from backcross, F_2 and F_3 genetic data. Genetics 32: 379-390. 1947.
7. Pearson, O. H. A dominant white flower colour in *Brassica oleracea* L. Amer. Nat. 63: 561-65. 1929.
8. Sears, E. R. Cytological phenomena connected with self-sterility in the flowering plants. Genetics 22: 130-181. 1937.
9. Wilson, Robert F. Horticultural colour charts 1 and 2. Henry Stone and Sons Ltd., England. 1938 and 1941.

A PRELIMINARY ESTIMATE OF THE AVERAGE INSOLATION IN CANADA[1]

By C. L. Mateer

Research Section, Meteorological Division, Department of Transport, Toronto, Ontario

[Received for publication September 28, 1955]

ABSTRACT

Charts of the estimated average insolation received over Canada during each month of the year have been prepared. In the construction of these charts, instrumental observations of insolation have been supplemented by estimates derived from empirical equations relating average insolation to average sunshine or cloudiness. In the winter months, the average insolation shows a distinct latitudinal gradient with values, in December, about 100 langleys per day along the southern border decreasing to zero in the region of the polar night. In the summer months, the latitudinal gradient disappears completely with, in June, areas of maximum (insolation $\geqslant 600$ langleys per day) in regions of low cloudiness and areas of minimum (insolation $\leqslant 500$ langleys per day) in the cloudy regions bordering on large bodies of water.

INTRODUCTION

From time to time, this Division has received requests from agriculturists, building engineers and others for information about solar radiation in Canada. To meet these requests, a study has been made of radiation climatology. An earlier paper (7) presented values of the average insolation[2] received in various parts of Canada during cloudless days in each month of the year. This paper presents an estimate of the average daily insolation over Canada, the average now being extended to include all days in each month rather than cloudless days only. It includes two empirical formulæ relating the proportion of bright sunshine in each month, and the duration of cloudiness, to the average insolation.

Insolation measurements have been made in Canada for periods exceeding four years at the following stations: Aklavik, Northwest Territories; Resolute, Northwest Territories; Edmonton, Alberta; Churchill, Manitoba; Winnipeg, Manitoba; Ottawa, Ontario, and Toronto, Ontario. However, the insolation data from these stations are inadequate for the construction of charts of average insolation in Canada on two counts. First, the period of record is too short and, second, the areal coverage does not embrace the entire country. To establish reliable averages of the insolation requires 25 to 30 years of observations and to cover the entire country satisfactorily necessitates a network of at least 100 stations.

To overcome the above difficulties, the following method was used: In southern Canada, there exists a network of approximately 85 stations recording the number of hours of bright sunshine each day and, for many of these stations, the period of record is in excess of 20 years. Therefore, empirical equations were derived relating sunshine and insolation at the insolation stations. These equations were then used to estimate long-term averages of insolation from the long-term averages of sunshine at each of the stations in the sunshine network. In the Canadian Arctic and sub-Arctic, average values of monthly cloudiness (for the period 1945-1954)

[1] Contribution from Department of Transport, Canada, published by permission of the Controller of Meteorological Services.
[2] Insolation is defined as the *in*coming *sol*ar radi*ation* incident on a horizontal surface. This includes both the direct solar and the diffuse sky radiation.

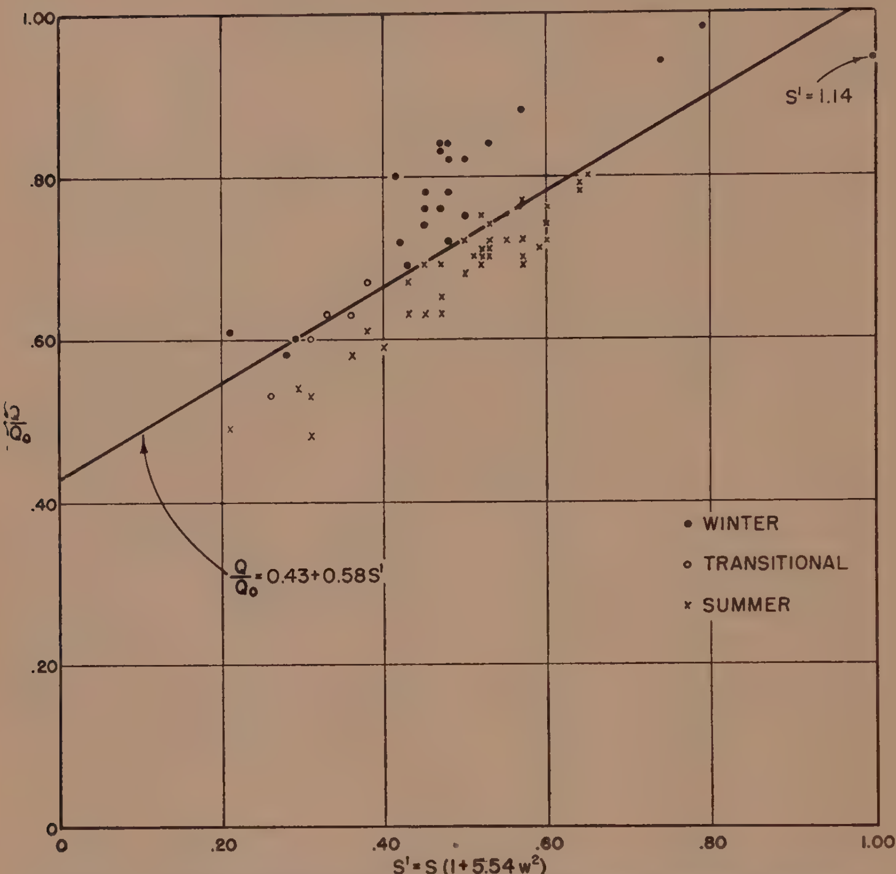


FIGURE 1. Scatter diagram showing the relation between average sunshine, S, (corrected) and the ratio, Q/Q_0, of average insolation to the average cloudless day insolation.

were determined for a network of 40 synoptic weather-reporting stations. Empirical equations were derived relating cloudiness and insolation at Aklavik, Churchill and Resolute and these equations were used to estimate the average insolation for each station in the cloudiness network. Charts of the average insolation over the continental United States have been prepared by Fritz and MacDonald (6) and a method of attack very similar to theirs is followed herein.

For convenience, we define the following basic quantities which apply to a given station and month:

Q—Average daily insolation* received at the earth's surface in ly./day.

Q_0—Average cloudless day insolation received at earth's surface in ly./day.

S—Number of hours of bright sunshine instrumentally recorded divided by the number of hours of possible sunshine.

C—Average fraction of the daytime sky obscured by cloud.

w—The fraction of the total daylight period during which the sun is less than 5° above the horizon.

* Insolation is measured in langley (ly.) where
1 langley = 1 gm. cal. per sq. cm. = 3·68 B.t.u. per sq. ft.

RELATIONS BETWEEN Q/Q_0 AND S

Ångström (1924) and others have suggested the following relationship between Q/Q_0 and S:

$$[1] \quad \frac{Q}{Q_0} = a + b\,S,$$

where a and b are empirical constants whose sum is usually taken as one.

It is necessary, at this point, to introduce a fairly well-known property of the Campbell-Stokes Sunshine Recorder. This recorder consists of a spherical glass lens which focuses the rays of the sun on a blue-tinted card. Bright sunshine is recorded when the intensity of the direct solar radiation is great enough to cause a "burn" on the record card. In short, the recorder will not, even under cloudless skies, usually begin to record bright sunshine until some time after sunrise and will cease to record some time before sunset (3, 4). On the average, the recorder does not record bright sunshine when the sun's elevation above the horizon is less than about 5°. During the Canadian winter, when the sun may be less than 5°

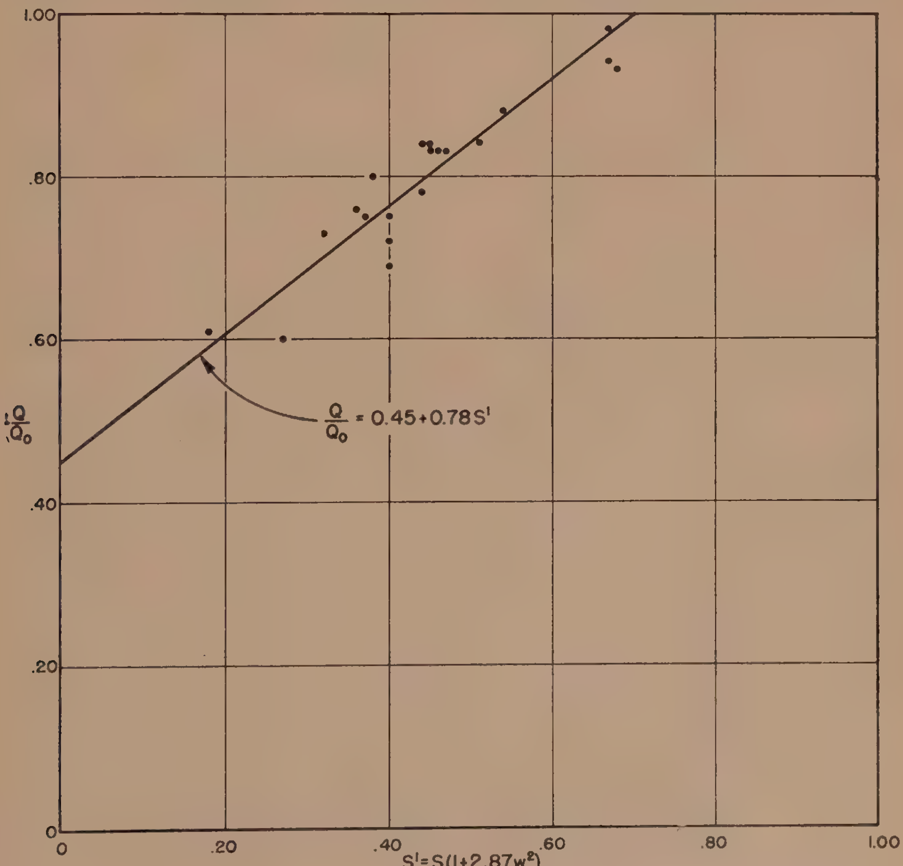


FIGURE 2. Scatter diagram showing the relation between average sunshine S, (corrected) and the ratio, Q/Q_0, of average insolation to the average cloudless day insolation for winter months.

above the horizon for a considerable portion of the day, some modification in equation [1] is necessary. A modification similar to one suggested by Brooks (1929) is used in the present work:

$$[2] \quad \frac{Q}{Q_0} = a + b\,S\,(1 + cw^2),$$

where a, b and c are empirical constants.

Values of Q and S were obtained, from Meteorological Division records, for the insolation stations at Churchill, Edmonton, Ottawa, Resolute, Toronto and Winnipeg. Values of Q_0 were obtained from the charts of cloudless day insolation and the ratio $\frac{Q}{Q_0}$ was computed for each month for each station. Figure 1 shows a scatter diagram of the values of $\frac{Q}{Q_0}$ plotted against $S' = S\,(1 + 5{\cdot}54\,w^2)$. The corresponding equation derived by the method of least squares is:

$$[3] \quad \frac{Q}{Q_0} = {\cdot}43 + {\cdot}58\,S\,(1 + 5{\cdot}54\,w^2)\ .$$

The multiple correlation coefficient between $\frac{Q}{Q_0}$, S and S w^2 is $0{\cdot}79$ and the standard error of estimating $\frac{Q}{Q_0}$ from this equation is $\cdot 064$. It was noted that the equation usually predicted too low values for Q/Q_0 in the winter and too high values in the summer (see Figure 1). Two explanations may be put forward for the too low values of Q/Q_0 predicted in the winter. When snow cover is present along with thin high cloud and/or "scattered" to "broken" middle or even low cloud, some solar radiation may be "trapped" between the highly reflecting snow surface and the cloud. Multiple reflections may then increase the observed insolation to somewhere near the cloudless day value. However, the cloud will cause interruptions in the sunshine record and may even stop the record entirely. Thus we may have a relatively high value of Q/Q_0 associated with a relatively low value for S. The second possibility is related to the observational technique with the sunshine recorder. The spherical glass lens of the recorder may become covered with snow or ice during a period of precipitation or with frost during the night. This coating on the glass lens may prevent the recording of bright sunshine. Such conditions may not occur frequently because the sunshine card must be changed each night and the glass lens would be cleared at that time. However, this difficulty will invariably result in S being too low. For these reasons, it was assumed that snow cover was the influencing factor and months were separated out into three groups: "months with snow cover" (winter), "months without snow cover" (summer) and "transitional" months.

Figure 2 shows a scatter diagram of the values of Q/Q_0 plotted against $S' = S\,(1 + 2{\cdot}87\,w^2)$ for the winter months. The corresponding equation is:

$$[4] \quad \frac{Q}{Q_0} = {\cdot}45 + {\cdot}78\,S\,(1 + 2{\cdot}87\,w^2)\ .$$

The multiple correlation coefficient is now $\cdot 96$ and the standard error of estimate is $\cdot 028$.

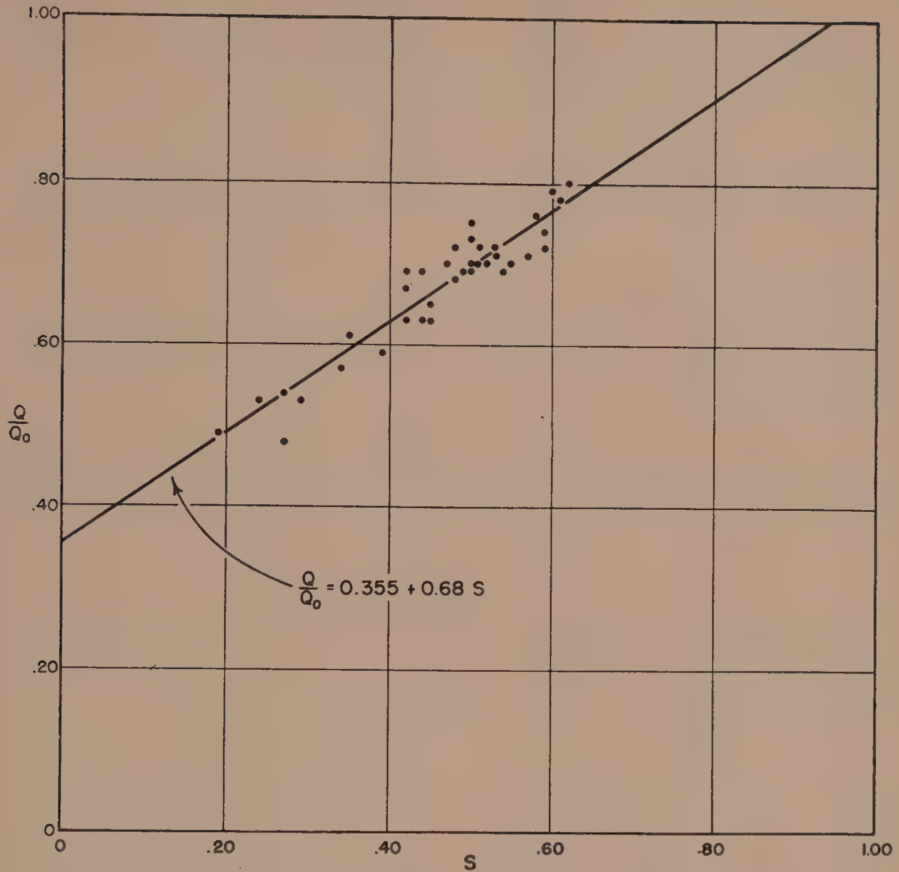


FIGURE 3. Scatter diagram showing relation between average sunshine, S, and the ratio, Q/Q_0, of average insolation to the average cloudless day insolation for summer months.

Figure 3 shows a scatter diagram of the values of $\frac{Q}{Q_0}$ plotted against S for the summer months. The corresponding equation is:

$$[5] \quad \frac{Q}{Q_0} = \cdot 355 + \cdot 68\, S.$$

The correlation coefficient is ·93 and the standard error of estimate is ·029. No significant increase in accuracy was achieved by using a more complex equation analogous to [4] for the summer months. It may be noted that equation [5] is very similar to

$$[6] \quad \frac{Q}{Q_0} = \cdot 35 + \cdot 61\, S$$

derived by Fritz and MacDonald for 11 stations in the continental United States. The coefficient of S in [5] is somewhat higher than the corresponding coefficient in [6]. This may be attributed to different methods of observation of S in the United States and in Canada. In the United States, the period of non-recording of the Maring-Marvin Sunshine Recorder near

sunrise and sunset is corrected for by the observer who adds an appropriate amount to the instrumentally recorded sunshine. According to Brooks and Brooks the difference is such that, on the average,

$$[7] \quad S_{US} = 1 \cdot 11 \, S_{CAN} .$$

If we equate the right-hand sides of equations [5] and [6], we get

$$\cdot 61 \, S_{US} = \cdot 68 \, S_{CAN}, \text{ or}$$

$$[8] \quad S_{US} = \cdot\frac{68}{61} S_{CAN} = 1 \cdot 11 \, S_{CAN}$$

which is in exact agreement with [7]. In short, equations [5] and [6] are compatible.

It must be emphasized that the above equations are derived from monthly averages of Q/Q_0 and S and should not be applied to daily values of these quantities.

RELATIONS BETWEEN Q/Q_0 AND C

For the months February through October, average cloudiness was computed for each month of insolation record at Aklavik, Churchill and

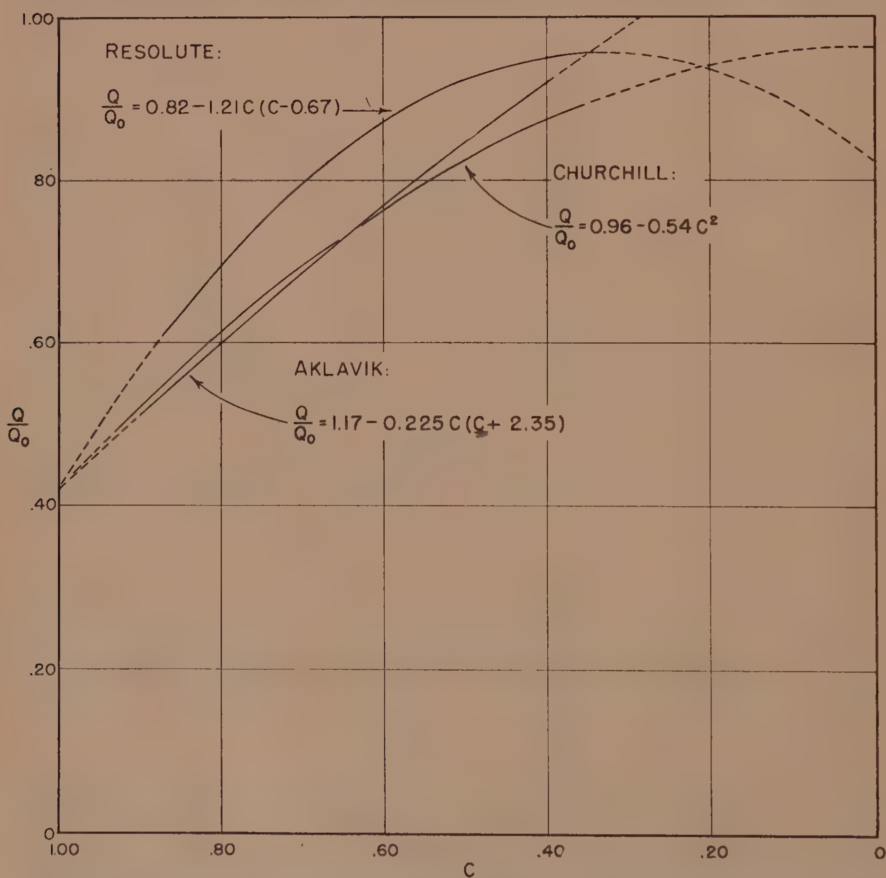


FIGURE 4. Diagram showing the relation between average cloudiness, C, and the ratio, Q/Q_0, of average insolation to the average cloudless day insolation at Aklavik, Churchill and Resolute.

Resolute. The cloud data were obtained from the publications and official records of the Meteorological Division. Only cloud observations taken during the day and just before dawn or after sunset were used in computing these averages.

Values of Q/Q_0 and C were tabulated for each month of record (February through October) and the following equations were derived by the method of least squares:

$$[9] \quad \text{Aklavik:} \quad \frac{Q}{Q_0} = 1{\cdot}17 - {\cdot}225C\,(C + 2{\cdot}35)$$

$$[10] \quad \text{Churchill:} \quad \frac{Q}{Q_0} = {\cdot}96 - {\cdot}54C^2$$

$$[11] \quad \text{Resolute:} \quad \frac{Q}{Q_0} = {\cdot}82 - 1{\cdot}21C\,(C - {\cdot}67)\,.$$

These equations have been plotted in Figure 4 and that portion of each curve extending beyond the observational data has been indicated by a dashed line. The multiple correlation coefficients between $\frac{Q}{Q_0}$, C and C^2 are, for each of these stations, respectively, ·79, ·86 and ·80 and the standard errors of estimate are ·074, ·066 and ·087. The correlations between cloudiness and insolation are not so high as the sunshine-insolation correlations. The reason is fairly clear: insolation and sunshine measurements are integrated over the entire day whereas the cloud averages are simply averages of observations taken at definite times. Significant changes in cloudiness which may occur between observation times are reflected in the Q values but not in the C values. However, the cloudiness method is the only one available at present for estimating the insolation in Arctic and sub-Arctic regions.

CALCULATION OF Q

For the 85 sunshine stations, values of S and w were tabulated for each month of the year. It was necessary to separate out winter, summer and transitional months for these stations. Accordingly, the following criteria were established by inspection of the data from the insolation stations:

Let D_i = the day of the year on which the first snow cover of one inch or more occurs on the average; D_f = the day of the year on which the last snow cover of one inch or more occurs on the average; T = the average monthly temperature. For a month to be classified as a winter month: $T < 25°F$, D_i must occur at least 10 days prior to the first of the month and D_f must be at least 10 days after the end of the month. If $T \leqslant 20°F$, the snow criteria may be reduced to 8 days. A month adjacent to a winter month may be classed as transitional provided $T \leqslant 35°F$. All other months are summer months.

A climatological publication of the Meteorological Division, and Boughner and Potter's (2) charts on snow cover, were used to classify each month at each station.

It is clear from Figures 2 and 3 that equations [4] and [5] do not give Q exactly. Suppose we follow the terminology of Fritz and MacDonald (6)

and let Q_r be the measured value of Q, S_r the corresponding value of S and let the value of Q computed by the appropriate equation ([4] or [5]) be designated $f(S_r)$. Then, in general $Q_r \neq f(S_r)$ and we may set $Q_r - f(S_r) = d_s$. This residual error, d_s, is ascribable to time of year and geographical location, factors not included in the original regression equations. It is, therefore, possible to interpolate between the insolation stations and apply these small corrections to the computed values of Q.

Values of d_s at the insolation stations were plotted on charts of Canada (one for each month and hereinafter designated as the working charts) and isopleths of d_s were drawn embracing that portion of Canada covered by the sunshine network. Values of Q were then computed for the sunshine stations (for transitional months, Q/Q_0 was estimated by averaging values obtained with [4] and [5]) and, after correction by the appropriate value of d_s, were plotted on the working charts. The corrections were small and usually less than $\cdot 05\ Q_0$.

For the insolations stations, in a few cases, S_r differed slightly from the long-period average of S. In these cases, small adjustments, as given by [4] or [5], were made to the observed insolation. In no case did these adjustments exceed 5 per cent of Q.

For the 40 Synoptic weather-reporting stations in the Arctic and sub-Arctic, a procedure similar to the above was followed. Average values of C for each month (February through October) were computed. Corresponding values of Q/Q_0 were read off from Figure 4. Now the three curves on this diagram do not coincide and the value of Q/Q_0 was selected by appropriate interpolation. For the most northerly Arctic stations, the Resolute curve was used. For stations in the south Arctic the values of Q/Q_0 selected were between the three curves and, in the sub-Arctic, closest to the Aklavik and Churchill curves.

Following a terminology similar to that used for the sunshine-insolation computations, we have $d_c = Q_r - f(C_r)$. For stations at which both sunshine and cloudiness are observed (but not insolation) it was assumed that the sunshine computation of Q was more nearly correct and we define $(d_c) = d_s + f(S_r) - f(C_r)$. Using this technique, d_c or (d_c) values were available for six stations: Aklavik, Churchill, Coppermine, Goose, Port Harrison and Resolute. These corrections were plotted on the working charts and isopleths of d_c were drawn. The final values of Q, after correction by d_c, were plotted on the working charts.

In order to draw isolines in the southernmost part of Canada, it was necessary to estimate values of Q in the northern United States. For most regions this could be done by reference to the charts of Fritz and MacDonald (6). However, this was not possible in the Great Lakes region. In this region, the pyrheliometers have been located in cities which show, to at least some extent, an urban pollution effect. Furthermore, these charts have been based partially on insolation measurements at East Lansing, Michigan, which now appear non-representative.

It was necessary, therefore, to re-estimate values of Q_0 for sunshine stations in southwestern Ontario and Michigan. In doing so, an attempt was made to eliminate the urban effects noticeable in the Toronto, Ontario, data. The data for Sault Ste. Marie, Michigan, and Put-in-Bay, Ohio,

were considered to be more representative of conditions as they would exist away from the immediate vicinity of industrial centres.

Values of Q were then recomputed for southwestern Ontario (from the new Q_0 values and the ratios Q/Q_0 already computed from [4] and/or [5]). Data for sunshine stations in Michigan were obtained from a publication of the U. S. Weather Bureau (9), Q/Q_0 values computed according to [6], and Q values computed using the new estimates for Q_0.

These values of Q were plotted on the working charts and isolines were drawn embracing Canada and the northernmost United States. On the final published charts (Figures 5-16), values of Q were plotted for insolation stations in Canada (square station symbol). In a few cases, computed values of Q were plotted for sunshine or cloud stations (round station symbol) where the isolines do not give an adequate picture—that is to say, where linear interpolation between isolines will not give the correct insolation value. In drawing the isolines, the values of Q plotted for Toronto were disregarded. These Toronto values ranged from 15-25 ly./day lower in December to 20-40 ly./day lower in June than representative Q values for the surrounding countryside.

DISCUSSION OF THE INSOLATION CHARTS

The average insolation charts show features similar to the charts of Q_0. During the winter months, with low solar elevations and short days, the insolation values are low ranging, in December, from about 100 ly./day along the southern border to zero in the region of the polar night. In the summer months, when the lower solar elevations in the north are compensated for by the longer days, the insolation values are fairly high and the latitudinal gradient of the winter is absent. The most important controlling features are cloudiness and atmospheric pollution. In June, for example, areas of maximum insolation ($\geqslant$ 600 ly./day) are located in Southern Alberta in the lee of the mountains, in the Baffin Island interior and in the very far north. Areas of minimum ($\leqslant$ 500 ly./day) are located near the very large bodies of water.

The values presented in these charts are likely adequate for general agricultural and building research studies. However, they are not adequate for a full consideration of the energy budget of the earth and the atmosphere. For this latter purpose, consideration must be given to surface albedo (surface reflecting power) which is usually somewhat greater for larger angles of incidence. In short, although the summer insolation appears fairly evenly distributed over all latitudes, the so-called "heat equator" will still be located at about 40° or 45° North latitude.

Considering instrumental errors in the measurement of insolation as well as errors in the estimation of Q from the empirical equations, the accuracy of the charts for points at which sunshine is measured is likely within about 5-10 per cent. For the Arctic and sub-Arctic stations and for points at which insolation was not computed, the errors may be a little larger. In regions where the isolines are most uncertain and where they cross large bodies of open water, the isolines are shown as dashed lines. Other areas where the isolines should be treated with caution are where abrupt local changes in average cloud cover, atmospheric pollution, ground

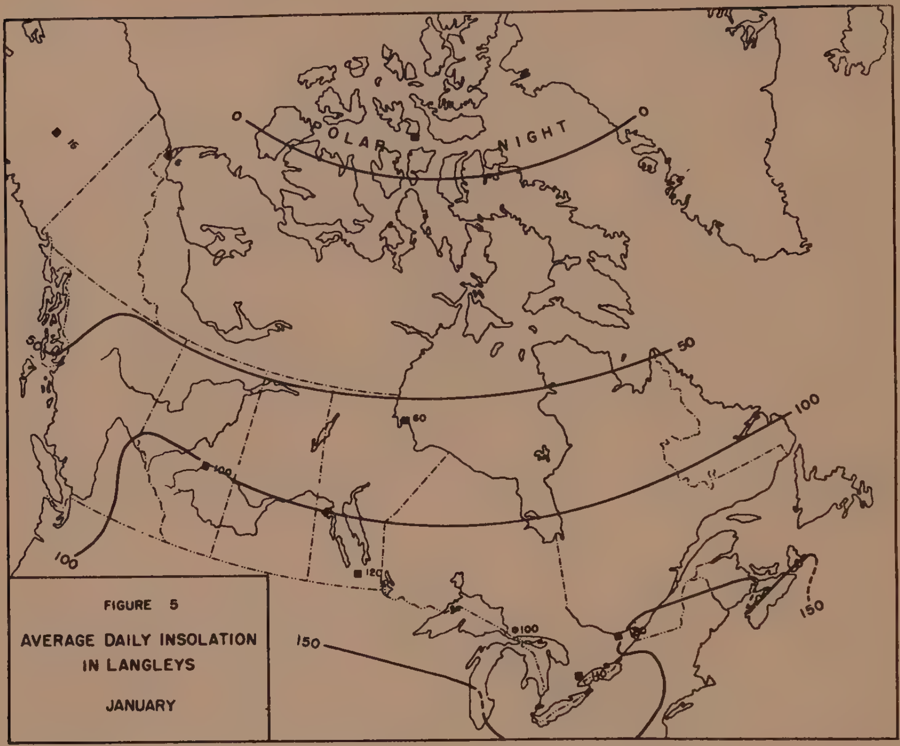


FIGURE 5

AVERAGE DAILY INSOLATION IN LANGLEYS

JANUARY

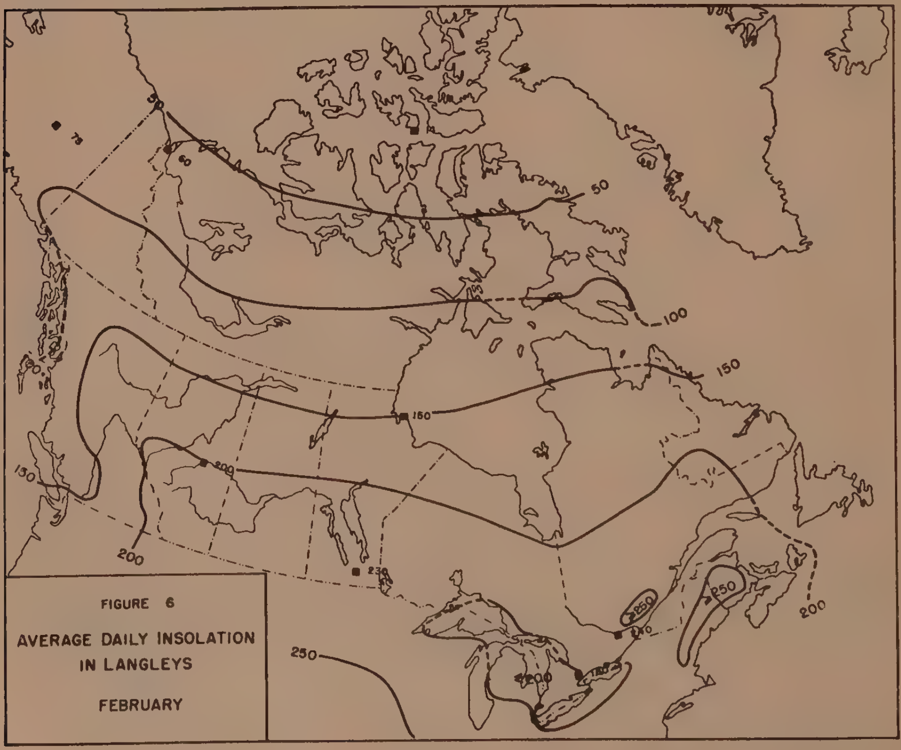


FIGURE 6

AVERAGE DAILY INSOLATION IN LANGLEYS

FEBRUARY

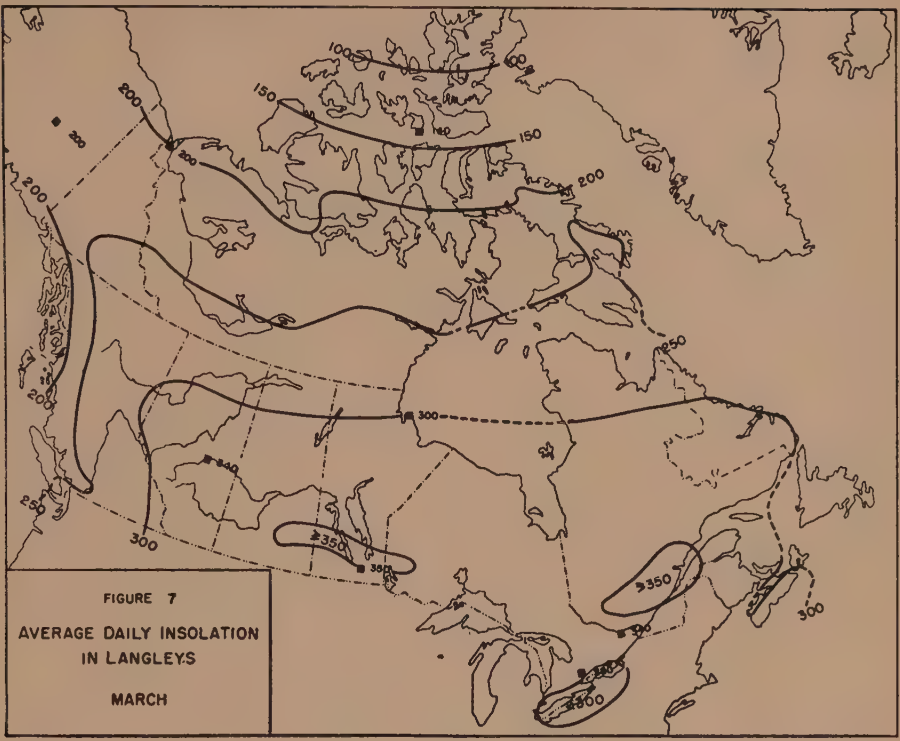


FIGURE 7

AVERAGE DAILY INSOLATION IN LANGLEYS

MARCH

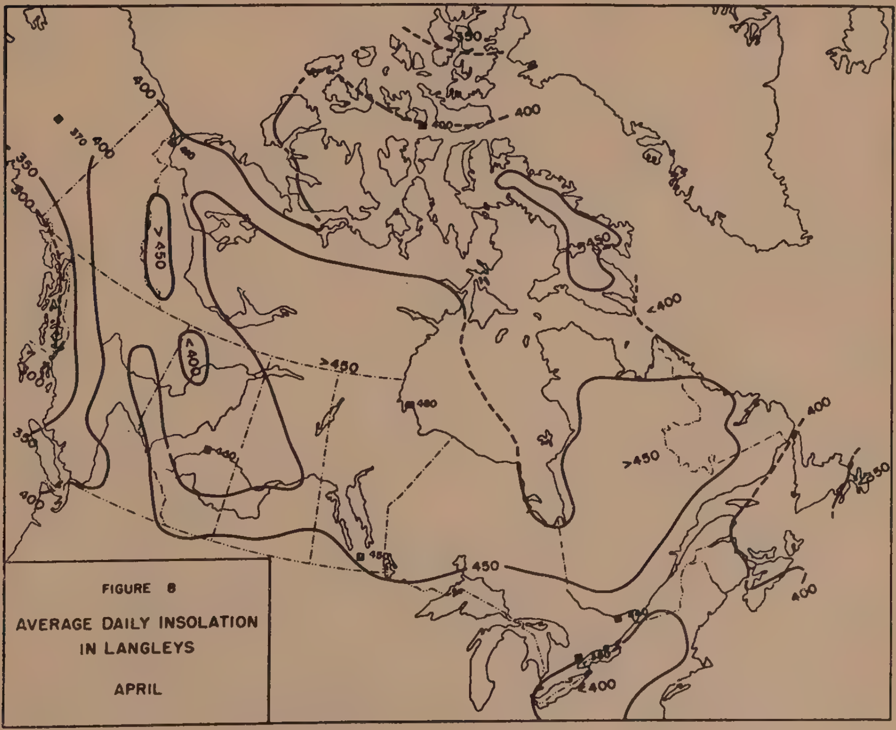


FIGURE 8

AVERAGE DAILY INSOLATION IN LANGLEYS

APRIL

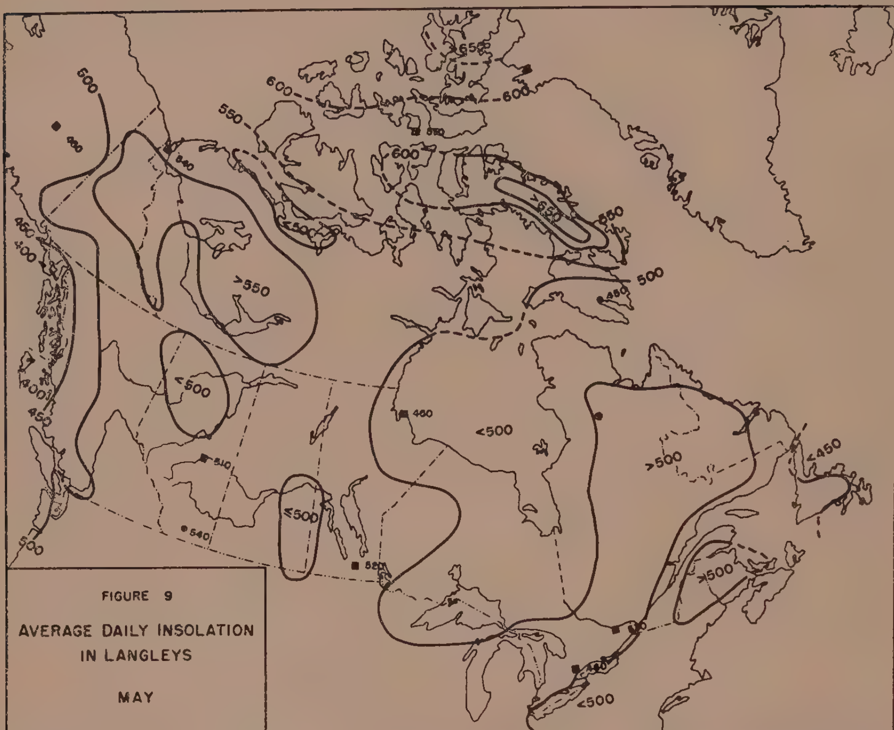


FIGURE 9

AVERAGE DAILY INSOLATION IN LANGLEYS

MAY

FIGURE 10

AVERAGE DAILY INSOLATION IN LANGLEYS

JUNE

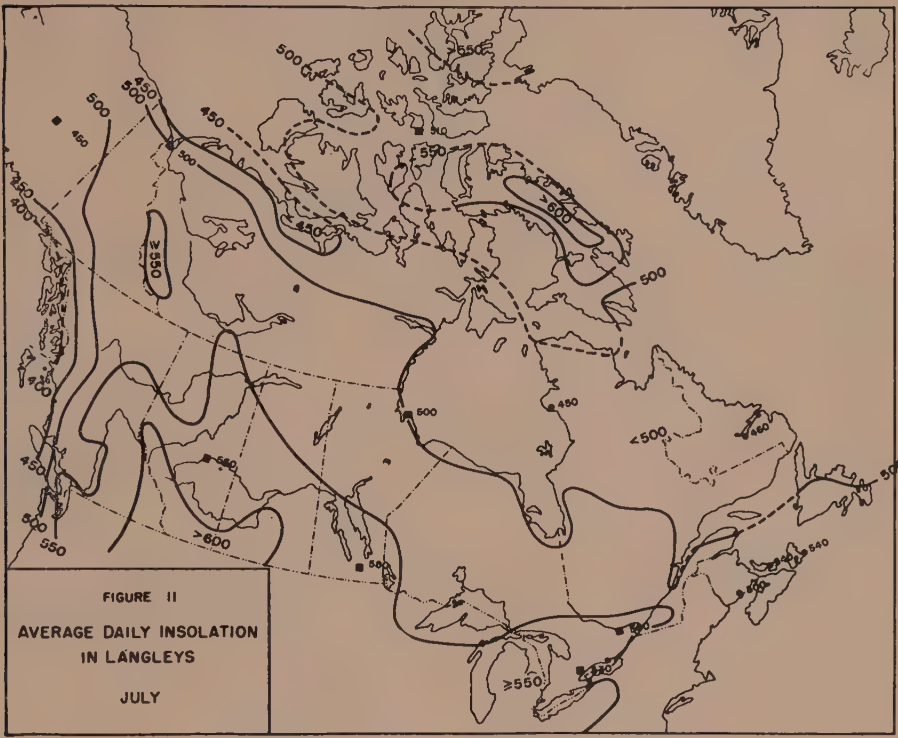


FIGURE 11
AVERAGE DAILY INSOLATION
IN LANGLEYS
JULY

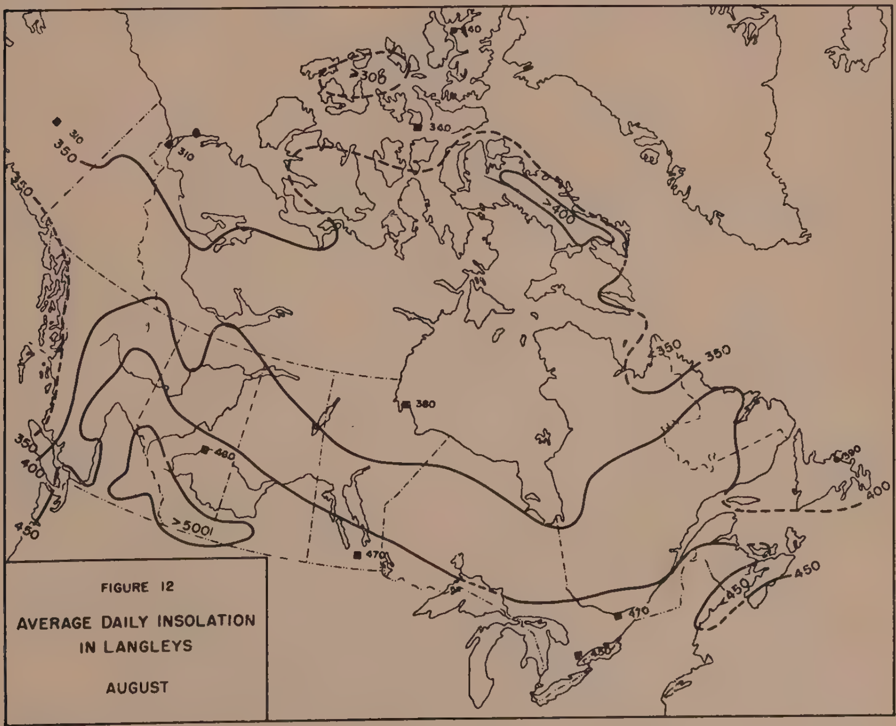


FIGURE 12
AVERAGE DAILY INSOLATION
IN LANGLEYS
AUGUST

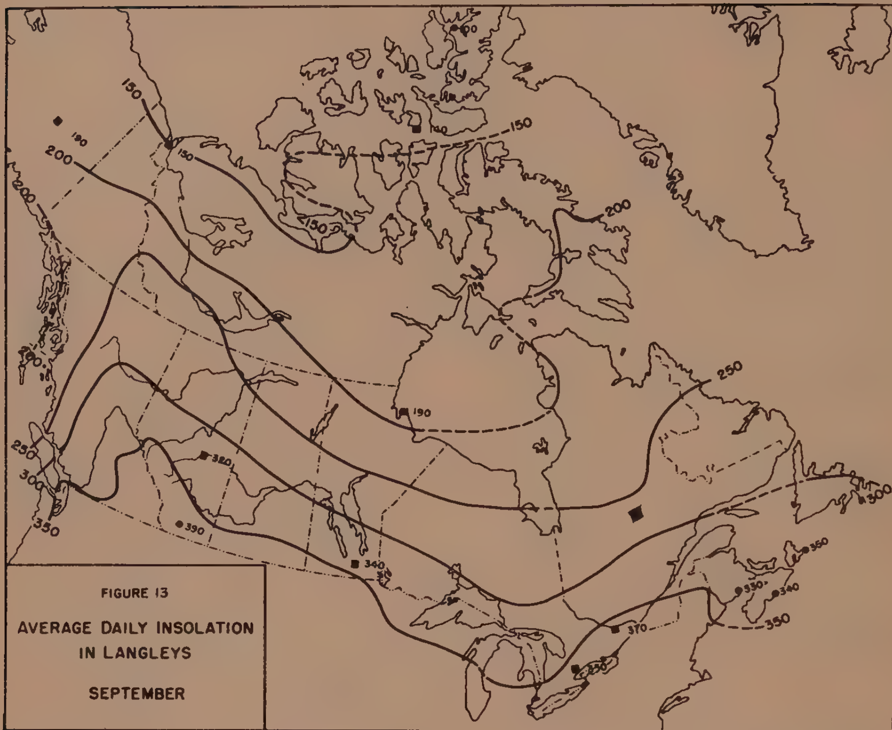


FIGURE 13

AVERAGE DAILY INSOLATION IN LANGLEYS

SEPTEMBER

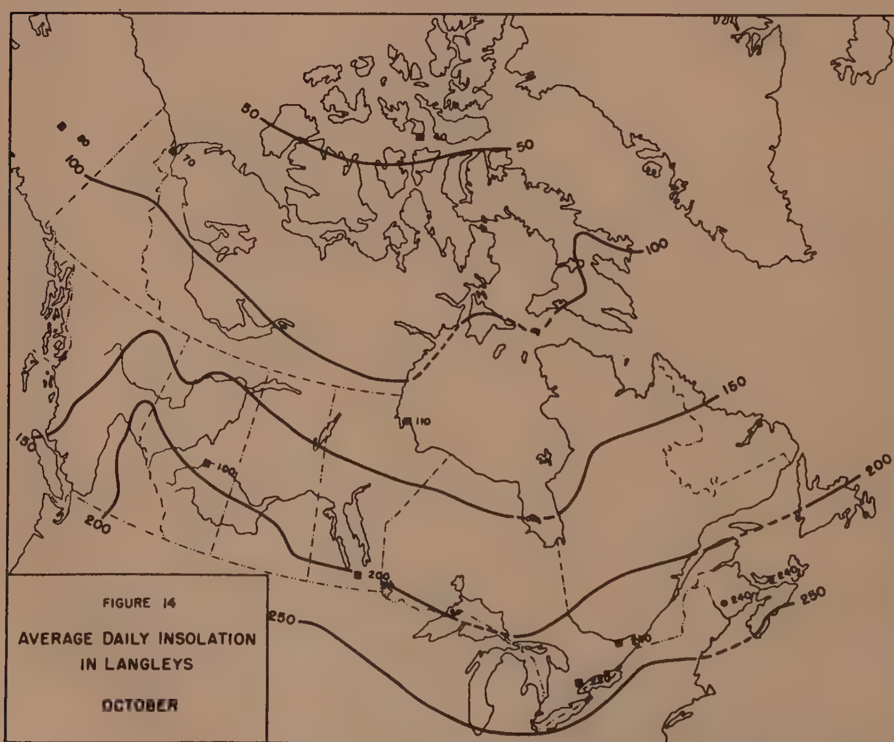


FIGURE 14

AVERAGE DAILY INSOLATION IN LANGLEYS

OCTOBER

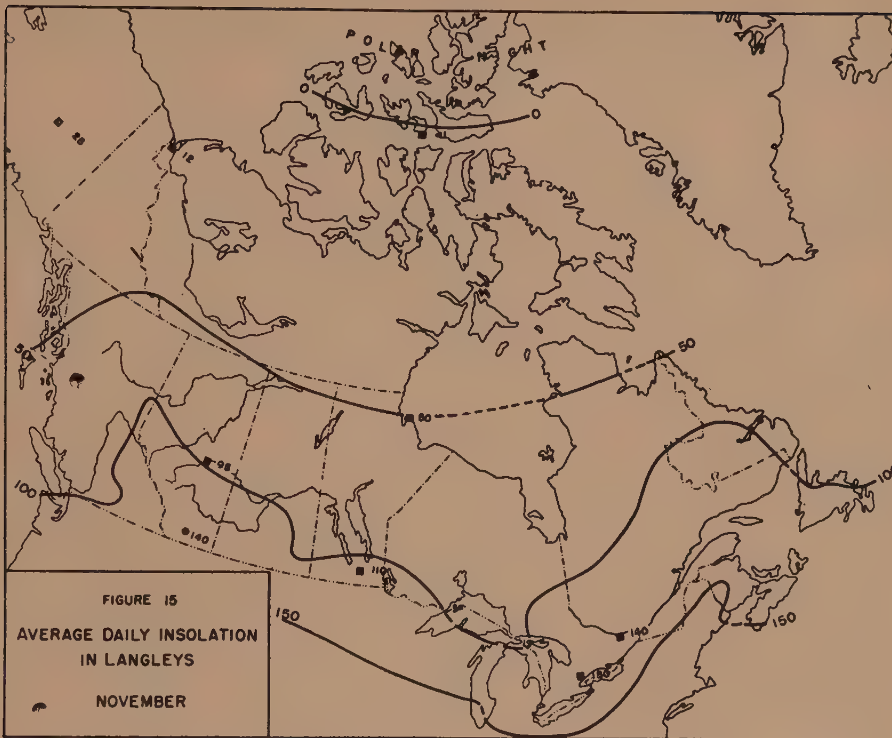


FIGURE 15

AVERAGE DAILY INSOLATION IN LANGLEYS

NOVEMBER

FIGURE 16

AVERAGE DAILY INSOLATION IN LANGLEYS

DECEMBER

elevation and/or ground reflection occur. Such areas are mountainous regions, coastal regions, and in large cities.

ACKNOWLEDGEMENT

The author wishes to acknowledge the numerous helpful discussions with Warren L. Godson, Superintendent of Atmospheric Research of the Meteorological Division.

REFERENCES

1. Ångström, A. Solar and terrestrial radiation. Quart. J. Roy. Meteor. Soc. 50: 121. 1924.
2. Boughner, C. C., and J. G. Potter. Snow cover in Canada. Weatherwise 6: 155. 1953.
3. Brooks, C. E. P. The comparison of sunshine recorders of the Campbell-Stokes type. Meteor. Office, London, Prof. Note 53. 1929.
4. Brooks, C. F., and E. S. Brooks. Sunshine recorders: A comparative study of the burning glass and thermometric systems. J. Meteor. 4: 105. 1947.
5. Climatic summaries for selected meteorological stations in the Dominion of Canada, Vol. I. Meteor. Div., Toronto.
6. Fritz, S., and T. H. MacDonald. Average solar radiation in the United States. Heating and Ventilating 46 (7): 61. 1949.
7. Mateer, C. L. Average insolation in Canada during cloudless days. Can. J. Tech. 33: 12. 1955.
8. Monthly record of meteorological observations in Canada. Meteor. Div., Toronto. 1945-1954.
9. Sunshine and cloudiness at selected stations in the United States, Alaska, Hawaii, and Puerto Rico. U.S. Weather Bureau, Tech. Paper 12. 1951.

SWEET CHERRY FOLIAGE INDICATOR HOSTS FOR THE VIRUS THAT CAUSES LITTLE CHERRY[1]

J. M. Wilks[2] and M. F. Welsh[3]

Plant Pathology Laboratory, Summerland, British Columbia

[Received for publication May 19, 1955]

ABSTRACT

Certain sweet cherry varieties and seedlings have been shown to display a foliage reaction to the little cherry virus. The symptom is a reddening of the leaf laminae. Some of the varieties and seedlings also show chlorotic mottles and necrotic shot holing. These host reactions are not produced by the latent ring spot viruses that are common contaminants in trees infected with little cherry. Other viruses tested, including those of sour cherry yellows, mora, and rusty mottle, have failed to induce the red leaf symptoms.

INTRODUCTION

Investigations of the virus disease little cherry have been hampered by the lack of suitable experimental material. This disease, which is limited to the Kootenay region of British Columbia, was first observed in 1933 (1). The spread from tree to tree and from orchard to orchard was so rapid that by 1949 very few healthy trees remained in Kootenay districts. This situation has not only limited the number of experimental trees that can be used, but has rendered difficult the protection of the few trees remaining available. Progress in the study of the disease has been hindered further by the nature of little cherry symptoms which in the common commercial varieties are expressed only in maturing fruits during a short period of the year, and which are frequently not sufficiently characteristic to preclude their confusion with symptoms of other diseases. For these reasons, the scale of experiments has been seriously reduced. An urgent need for foliage indicator hosts has been recognized and a search for them has been conducted.

EXPERIMENTAL METHODS AND RESULTS

During the course of varietal resistance studies, certain varieties and seedlings when inoculated with little cherry virus developed a characteristic foliage reaction. The clones under test were propagated on Lambert trees affected with little cherry. In 1948 strong red foliage pigmentation was observed during the months of July and August in all branches of two of these propagated clones. These were the variety Star and the seedling S-6-6 (7). The same symptoms have been displayed in these branches each year since that time. No such pigmentation has been produced in the Lambert foliage or the foliage of other varieties budded to the same trees. Parent trees of Star and S-6-6(7) growing on the Experimental Farm at Summerland have not displayed foliage reddening during the summer months, although both varieties produce a strong red foliage colour immediately before autumn defoliation.

[1] Contribution No. 1461 from the Botany and Plant Pathology Division, Science Service, Canada Department of Agriculture, Ottawa, Ontario. Portion of a thesis submitted by the senior author to the Graduate School, Oregon State College, in partial fulfilment of the requirements for the degree of Doctor of Philosophy.
[2] Assistant Plant Pathologist.
[3] Senior Plant Pathologist.

TABLE 1.—SYMPTOMS IN SWEET CHERRY VARIETIES AND SEEDLINGS PRODUCING A RED LEAF REACTION TO LITTLE CHERRY VIRUS

Variety	Intensity of reddening*	Chlorotic or necrotic mottles	Nature of red leaf symptoms
S-5-11(7)	Slight	Mild, mostly on terminal leaves	Mostly interveinal; present first on upper surface
S-3-18(7)	Slight	Slight on one tree	Light red colour, scattered over both leaf surfaces
S-3-3-(7)	Slight	None	Mostly on leaf margins and upper surfaces
S-8-14(SF)	Slight	None	Interveinal, mostly on upper surface
S-9-10(SF)	Slight	Some	Mostly on upper surface developing interveinally
Velvet	Slight	Chlorotic mottle and necrotic shot hole	Interveinal on both surfaces developing from margins inward
S-10-14(7)	Slight	Some chlorotic mottle	Interveinal; mostly on upper surface
S-3-7(7)	Slight	None	On both surfaces, but more severe on under surface
S-6-7(7)	Moderate	Some	Interveinal; first on lower surface, later more severe on upper surface
Sam	Moderate	Some lace leaf on terminal leaves	Interveinal; mostly on upper surface
S-7-1(SF)	Moderate	None	General on both surfaces; some leaves show stippled blotchy appearance
Bear River Seedling	Moderate	None	Not interveinal; marginal and blotchy on upper surface, general on under surface
S-7-10(SF)	Moderate	None	Interveinal; mostly on under surface
S-5-19(7)	Moderate	None	On both surfaces; interveinal and along leaf margins
Black Oxheart	Moderate	Necrotic lesions, mostly terminal leaves	Interveinal; coalescing on margins; more severe on upper surface
S-5-4(SF)	Moderate	None	Interveinal; mostly on upper surface and along leaf margins
S-8-4(SF)	Moderate	Present on basal leaves	Interveinal; more severe on terminal growth and upper surface

TABLE 1.—SYMPTOMS IN SWEET CHERRY VARIETIES AND SEEDLINGS PRODUCING A RED LEAF REACTION TO LITTLE CHERRY VIRUS—*Concluded*

Variety	Intensity of reddening*	Chlorotic or necrotic mottles	Nature of red leaf symptoms
S-6-6(7)	Severe	Strong chlorotic, plus some necrotic lesions	Mostly interveinal; first apparent on upper, later equally distributed on both surfaces
Star	Severe	Some of both, mostly chlorotic	Interveinal; almost entirely on upper surface
S-5-16(7)	Severe	None	Interveinal and more intense on under surface; general on upper surface
S-7-9(SF)	Severe	Necrotic lesions	Deep red, solid on upper surface except for veins; light red along margins of under surface
S-7-11(SF)	Severe	None	Interveinal, but coalescing along margins; mostly on upper surface

* *Slight:* Light red symptoms on one or both leaf surfaces.
Moderate: Deeper red colouration.
Severe: Dark red colour developed on one or both surfaces.

In Star (*see Figure 1*), the strongest symptoms develop in the basal leaves of the current season's growth, and become progressively less intense in the leaves toward the tip of the branch. The upper surface of severely affected leaves displays a solid red colour around the margins, and colour of gradually decreasing intensity toward the midrib. In less severely affected leaves the pigmentation is confined to interveinal areas; the main veins and adjacent tissue, and sometimes even the fine veinlets, remain free from pigmentation. The undersurface of all leaves shows less red colouration, often only a stippling of red in the interveinal areas.

In S-6-6(7) (*see Figure 2*), the development of the reddening is similar to that in Star, but the colour is less intense. The reddening first becomes apparent on the upper surface, but later in the summer it becomes equally strong on both leaf surfaces. Accompanying symptoms in this variety include strong chlorotic mottles, and necrotic lesions which usually drop out to give the leaf a shot hole appearance.

Since the first appearance of red leaf symptoms in 1948, observations have been extended through the 54 varieties and seedlings that were included in varietal resistance trials. Twenty-six of these have displayed the red leaf symptoms in varying degrees of severity. The 22 showing strongest colouration were subjected to further study during the 1951-54 seasons. Two to five grafts of each variety or seedling were available for observation. In addition, the symptoms were observed in 20 trees of Star, 4 trees of Sam and 4 trees of S-6-6(7), which had been established on Mazzard understock and inoculated with little cherry virus. Table 1 lists the 22 varieties and seedlings, with the types of symptoms expressed. In

most of them the reddening developed on both surfaces of the leaf, but it was more strongly expressed on the upper surface. In those listed as slight, the reddening was usually confined to the upper surface. Most varieties expressed the reddening interveinally, but in certain clones the colour developed over the entire leaf surface, including the veinlets. In some varieties the reddening was confined to a narrow margin bordering the veins.

The time of first expression, and the time and intensity of maximum expression of the reddening, appeared to depend on weather conditions; periods of sunny days and cool nights proved most favourable. Usually the symptoms were apparent about the beginning of July, and reached maximum intensity by the middle of September. Uninoculated trees showed little or no red colouration until late October.

To demonstrate that this reaction is specific for little cherry, it has been necessary to show that it cannot be produced by the latent viruses that occur commonly in sweet cherry trees. The most common of these are the ring spot viruses, which have occurred as contaminants in all the little cherry sources used. The possibility that these viruses were responsible for the red leaf reaction was tested in two ways: (a) by tests made for the presence of ring spot viruses in uninoculated trees of these indicator varieties and seedlings, and (b) by tests for the reaction of these varieties to ring spot viruses introduced into them from other trees.

Indexing of source trees of fourteen of these varieties and seedlings on Shiro-fugen flowering cherry (3) showed that all except S-3-18(7) carried a ring spot virus.

Three trees of Star were inoculated in 1951 with Lambert buds carrying ring spot virus, but free from little cherry virus. In the ensuing two seasons there was no development of the red leaf symptoms that invariably follow inoculation of this variety with little cherry virus.

Other viruses that have been inoculated into Star are those causing western X little cherry, mora disease, rusty mottle and sour cherry yellows. These tests were carried out in a greenhouse at Corvallis, Oregon, in January, 1953. Each virus was inoculated into four 2-year-old Star trees by budding. Western X little cherry, which has not been found in the Kootenays within the range of the little cherry disease, produced red leaf symptoms that are described in a forthcoming paper. The trees inoculated from sources containing mora disease, rusty mottle, and sour cherry yellows plus ring spot virus, produced no red leaf symptoms in 1953; when re-established in the greenhouse in 1954, the trees displayed symptoms characteristic of these diseases, but no red leaf symptoms.

DISCUSSION

The demonstrated host range of the virus causing the little cherry disease is confined to sweet and sour cherry and the native cherry (*Prunus emarginata* var. *mollis* (Dougl.) Brewer) (2). The commercial varieties of sweet and sour cherry grown in the Kootenays have displayed symptoms only in mature fruits. The native cherry carries the virus without display-

FIGURE 1. Leaf symptoms in Star showing the distribution of the red pigmentation. Leaves on *left* from inoculated tree and leaf on *right* from uninoculated check.

FIGURE 2. Foliage symptoms in the seedling S-6-6(7) showing the chlorotic mottle and necrotic shot hole which are produced in addition to the reddening in this seedling. Leaf at *right* is from uninoculated tree.

ing symptoms. New or uncommon varieties of sweet cherry have, therefore, been utilized in the search for indicator hosts. The variety Star, and the other varieties and seedlings that have been tested during these investigations are either recent originations of the Summerland Experimental Farm or uncommon varieties that have not been grown previously within the range of the little cherry disease.

Strong evidence has been obtained that the red leaf reaction of certain of these varieties and seedlings is specific for the causal virus of little cherry, even though the presence of latent viruses in all tested source trees of little cherry has rendered impossible the subjection of the indicators to uncontaminated sources of little cherry virus. All sources of little cherry virus used, regardless of the contaminants present, have given the same reaction in a given indicator. Moreover, it has been possible to test samples from cherry sources that carry ring spot viruses, and sour cherry yellows virus, but are free from little cherry virus, and these have failed to give the red leaf reaction. No other known latent viruses are sufficiently common in sweet cherry to be suspect. Moreover, it is unlikely that a latent virus would be present in all little cherry sources tested, but absent in all sources that were free from little cherry virus.

The chlorotic and necrotic lesions that accompany the leaf reddening in some of the indicator varieties and seedlings resemble strongly the symptoms of the shock stage of necrotic ring spot infection. However, the symptoms are recurrent in trees infected with little cherry virus, and are absent in trees of the same varieties infected with ring spot viruses alone. Therefore, these symptoms appear to be as specific as the reddening symptoms in demonstrating the presence of little cherry virus.

Foliage reddening has not been recorded as the symptom of any virus disease of sweet or sour cherry, although it may be compared to the reaction produced when choke cherry is inoculated with western X little cherry virus (4). The colouration provides evidence that the causal virus of little cherry disturbs carbohydrate levels in the foliage as well as the fruits of infected trees. Presumably this disturbance may be effected either by alteration of carbohydrate metabolism in the leaves, or by interference with translocation from leaves to fruits and other organs. Histological studies are in progress, to determine whether or not damage to the conducting tissues is evident in leaf petioles of diseased trees.

Because bearing trees are not required for the reading of symptoms these indicator hosts will have many uses in investigations of the little cherry disease. Large numbers of small trees, protected from natural infection in screen cages, can be substituted for the limited numbers of bearing orchard trees that have been available. Alternatively, buds of these indicator varieties can be established on seedlings used in tests of seed transmission, or on trees of commercial varieties in which vector-suppression spray tests are being conducted. The indicators provide the additional advantage of easy symptoms diagnosis over a longer season than that provided by symptoms in ripe fruits.

REFERENCES

1. Foster, W. R., and T. B. Lott. Little cherry, a virus disease. Sci. Agr. 27: 1-6. 1947.
2. Foster, W. R., T. B. Lott, and M. F. Welsh. Little cherry. Virus diseases and other disorders with viruslike symptoms of stone fruits in North America. U.S. Dept. Agr. Handbook 10, pp. 126-129. 1951.
3. Milbrath, J. A. Selecting stone fruit trees free from virus diseases. Bull. 522, Agr. Expt. Sta., Oregon State College, Corvallis, Oreg. 1952.
4. Reeves, E. L., Earl C. Blodgett, T. B. Lott, J. A. Milbrath, B. L. Richards, and S. M. Zeller. Western X-disease. Virus diseases and other disorders with viruslike symptoms of stone fruits in North America. U.S. Dept. Agr. Handbook 10, pp. 43-52. 1951.

THE PERENNIAL SOWTHISTLES IN NORTHEASTERN NORTH AMERICA[1]

W. SHUMOVICH AND F. H. MONTGOMERY[2]

Ontario Agricultural College, Guelph, Ont.

[Received for publication July 21, 1955]

ABSTRACT

A preliminary morphological and cytological study has been made of the perennial sowthistles, genus *Sonchus*, of eastern Canada and the northeastern States. Two species have been recognized, *S. arvensis* L., and *S. uliginosus* Bieb. The former has a somatic chromosome number of 54, which differs from previously published chromosome numbers for this species; the latter has a number of 36. This is a new chromosome complement in the genus.

Natural hybrids were found in the field, and experimental hybrids were produced in the greenhouse; these had a somatic chromosome complement of 45. Backcrosses between the hybrids and both parents formed a dysploid chromosome series of $2n = 36$ to $2n = 54$. An experimental cross between hybrids produced a similar chromosome series.

INTRODUCTION

The perennial sowthistles are common weeds in grainfields, recently abandoned fields, and along roadsides in Canada and the northern United States. Their golden-yellow, dandelion-like flowers, and white, golf-ball size fruiting heads are a familiar sight during summer and autumn.

Two kinds of perennial sowthistles are recognized; one has the peduncles and involucres of the heads covered with gland-tipped hairs, while in the other, the plants are glabrous. Both forms are of European or western Asiatic origin, and both have a wide distribution in the Old World. The distribution of these sowthistles in Canada has been discussed by Groh (6). His data indicate that at that time the glabrous form occurred "only sparingly in the east". Our distribution maps show that both species are common throughout the province of Ontario, and they have been observed in fields and along roadsides from Buffalo, New York, to the coast of Massachusetts. The glandular pubescent plants were first reported in America by Pursh in 1814 from Pennsylvania, and were called *Sonchus arvensis* L. This name has been used consistently, and for the large majority of glandular pubescent plants is the correct name to apply. It is shown in this paper, however, that not all specimens of this type are typical *S. arvensis*.

Fernald and Wiegand (4) noted glabrous sowthistles in Maine, and called them *S. arvensis* var. *glabrescens* Guenth., Grab & Wimm. In their paper, they also recorded other glabrous collections from Maine, Massachusetts, and Ohio, some dated as early as 1894. In 1921, Small (13) identified glabrous specimens collected by Rau in Pennsylvania as *S. uliginosus* Bieb. Fernald (3) considers that both these glabrous sowthistles are in our flora and that they have a similar distribution. Gleason (5) describes *S. uliginosus* and remarks: "Sometimes considered

[1] Contribution from Department of Botany, Ontario Agricultural College. Based on thesis submitted to the School of Graduate Studies, University of Toronto, in partial fulfilment of the degree M.S.A. by the senior author.
[2] Professor of Botany, Ontario Agricultural College.

conspecific with *S. arvensis*, in which case, it takes the name *S. arvensis* var. *glabrescens* Guenth., Grab. & Wimm". In Europe, Hallier (8), Hayek (9), and Hegi (10) place a glabrous form under *S. arvensis* var. *laevipes* Koch, and make *S. uliginosus* synonymous. They do not include the variety *glabrescens* in the synonyms.

This nomenclatural confusion, and the lack of understanding of the species, led the authors to make a study of the perennial representatives of the genus in northeastern North America to determine, *first*, the taxonomic relationship between the glandular pubescent and glabrous plants; and *second*, the correct epithet that should be applied to our glabrous sowthistles.

This study was further stimulated by the finding of apparent hybrids in fields where both glabrous and pubescent plants were present. These suspected hybrids were glandular pubescent, and were first distinguished by the small amount of pubescence on the peduncles and involucres. The authors were unable to find references in the literature of hybridization between these species of the genus, and wished to experimentally prove the formation of hybrids and to establish their origin.

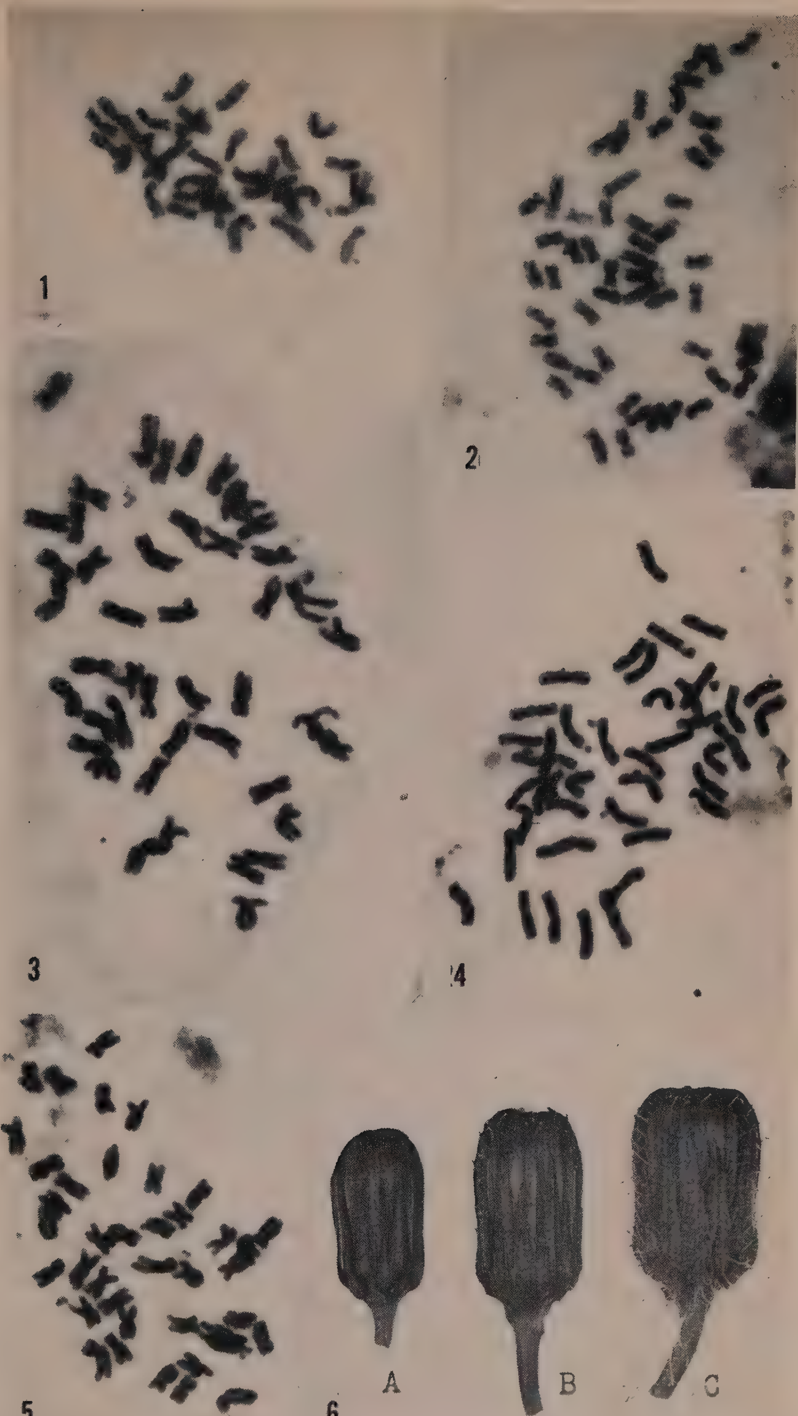
A review of cytological studies showed that there was disagreement as to the chromosome complement of *S. arvensis*. Wulff (15), Erlandsson (2) and Sakisaka (12) reported a haploid number of 32 for this species. Stebbins *et al.* (14) inferred that, since the basic number for the genus is 9, the haploid number of 36 should be considered. Askell Löve* was never able to observe 64 chromosomes in root-tips of *S. arvensis* in Iceland, and Löve and Löve (11) have reported a somatic chromosome number of "ca. 54". In this survey the somatic chromosome number for *S. arvensis* has been re-examined, and the chromosome numbers for the glabrous species and hybrids are reported for the first time.

MATERIALS AND METHODS

Collections of perennial sowthistles were made throughout most of the agricultural area of Ontario as a preliminary to morphological studies. The junior author also made a survey of the species in New York State and the New England States while on a field-trip through these states. The aboveground portions of the plants were pressed and filed in the herbarium of the Ontario Agricultural College; the underground parts were potted and grown in the greenhouse to provide material for experimental and cytological studies. Herbarium specimens were examined from the Department of Agriculture, Ottawa, Ont.; National Museum of Canada, Ottawa, Ont.; University of Toronto, Toronto, Ont.; Queen's University, Kingston, Ont.; University of Western Ontario, London, Ont.; McMaster University, Hamilton, Ont.; Ontario Agricultural College, Guelph, Ont.; Grey Herbarium, Harvard University, Boston, Mass.; Cornell University, Ithaca, N.Y.; Komarov Botanical Institute, Leningrad, S.S.S.R.; National Museum of Natural Science, Vajdahungadvara, Hungary; Slezske Museum, Opava, Czechoslovakia.

For cytological studies, excised root-tips were pretreated in paradichlorobenzene for 40 minutes. They were then washed for 10 minutes and fixed in acetic-alcohol, 2 parts absolute ethyl alcohol to 1 part glacial

* *Personal correspondence.*



FIGURES 1-5. Chromosomes in *Sonchus*. 1. *S. uliginosus*, $2n = 36$; 2. *S. arvensis*, $2n = 54$; 3. F_1 hybrid, $2n = 45$; 4. F_1 hybrid $\times$ *uliginosus*, $2n = 41$; 5. F_2 hybrid, $2n = 40$.

FIGURE 6. Buds just before anthesis showing differences in shape and size of heads and the number of glandular hairs. (*a*) *S. uliginosus*, (*b*) F_1 hybrid, (*c*) *S. arvensis*.

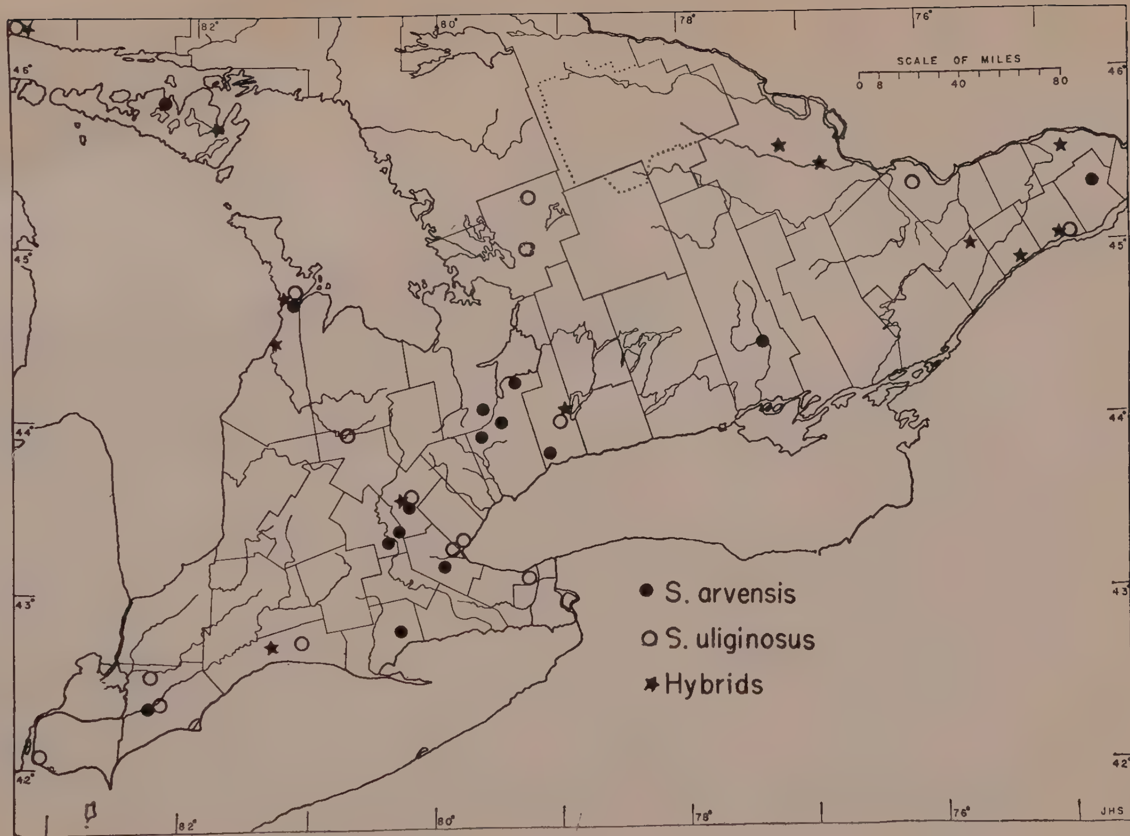


FIGURE 7. Map showing geographical origin of specimens of *S. arvensis*, *S. uliginosus* and hybrids examined cytologically.

acetic acid, for 30 minutes. Staining was done in leuco-basic fuchsin as outlined by Grun (6). The chromosomes were studied before making the slides permanent. To obtain cells with well separated chromosomes, selected cells were flattened by applying pressure with a needle while observing them through the low power of the microscope. The photomicrographs were made from the temporary slides, with suitable filters and with a 2-mm. apochromatic oil immersion objective, N.A. 1.32, and a 12X periplan ocular at a magnification of 2080X. The slides were later made permanent by flooding the slides and coverslips with 45 per cent acetic acid, then dehydrating in two changes of a mixture of equal parts xylol and absolute alcohol and mounting in DPX.

RESULTS

Comparison and measurement of glabrous plants, from over most of the area under survey, with respect to height, character of the leaves, phyllaries, heads and seeds did not bring out differentiating characters between plants that could be considered of a specific nature. Also specimens labelled *S. uliginosus* received from European sources did not differ basically from North American material that was named either *S. arvensis* var. *glabrescens* or *S. uliginosus*. On morphological grounds, it was concluded that only one species of smooth perennial sowthistle occurred within our area of study.

Cytological investigation of 22 plants from widely separated areas (Figure 7) showed that the glabrous sowthistle is a tetraploid, with a somatic chromosome number of 36 (Figure 1).

Typical *S. arvensis*, however, proved to be a hexaploid with a somatic number of 54 (Figure 2) instead of 64 as was previously reported (2, 12 and 15). The difference in chromosome numbers indicates that the glandular pubescent and the glabrous plants are distinct species, and that the glabrous plants should have a specific status.

A review of the literature showed that *S. uliginosus* Bieberstein (1), was the first validly published epithet to be applied to the species. We are, therefore, applying this name to the non-glandular pubescent perennial sowthistle, and placing *S. arvensis* var. *glabrescens* in synonomy. There seems no reason to suspect that the European specimens examined were not typical *S. uliginosus* which Hallier, Hayek, and Hegi considered synonymous with *S. arvensis* var. *laevipes* Koch. It would be consistent, then, to reduce the var. *laevipes* to synonymy also. As far as could be determined, no other glabrous variety of *S. arvensis* has been reported in Europe.

As mentioned above, where *S. arvensis* and *S. uliginosus* grew in the same fields, glandular specimens occurred that did not morphologically coincide with the characters of *S. arvensis*. The bud shape differed, and often the number of glandular hairs was reduced (Figure 6*b*). It was suspected that these plants were hybrids of the two species, and a cytological examination verified our supposition. These plants had a somatic chromosome number of 45. Hybridization experiments between the two species were carried on in the field and in the greenhouse, and it was found that the species could be crossed reciprocally and that F_1 plants were easily obtained.

All these experimental hybrids had the expected somatic chromosome number of 45 (Figure 3).

It was not always possible to differentiate between certain hybrids and *S. arvensis*, for cytological examination proved that even some of the densely glandular specimens were not true *S. arvensis*. Furthermore, their chromosome complement indicated that they were not F_1 hybrids, and it appeared that the differences in chromosome numbers were the result of backcrossing with the parents, or the intercrossing of hybrids. Cytological examination of seedlings from backcrosses of natural F_1 hybrids with one parent, *S. uliginosus*, showed that a dysploid series of chromosome numbers were produced (Table 1). The chromosomes of an F_1 hybrid × *S. uliginosus* are shown in Figure 4, $2n = 41$. One plant obtained from a cross of a natural F_1 hybrid with *S. arvensis* had a somatic chromosome number of 48. A sufficient number of experimental crosses have not been made to observe the full range of the chromosome numbers that may exist.

TABLE 1.—NUMBER OF SEEDLINGS AND THEIR CHROMOSOME NUMBERS OBTAINED FROM F_1 OF *S. uliginosus* × *S. arvensis* WITH *S. uliginosus*

Number of seedlings	$2n$ chromosome number
1	37
2	38
1	39
1	40
7	41
1	42
3	43

Six plants were obtained from the intercrossing of a natural F_1 hybrid and an experimental F_1 hybrid, and of these, 2 had a somatic number of 40 (Figure 5), 2 had 43, 1 had 45, and 1 had 46. Further evidence of backcrossing, or of hybrid intercrossing, was obtained from seeds collected from hybrids in fields at Lake Dore, Sault Ste. Marie and Owen Sound, where both parents were present. Although only 11 seedlings were obtained, the chromosome numbers were comparable with those found in experimental backcrosses and crosses of F_1 hybrids. Table 2 shows the chromosome numbers of these 11 plants.

TABLE 2.—CHROMOSOME NUMBERS OF SEEDLINGS FROM SEEDS COLLECTED IN MIXED STANDS OF SOWTHISTLES

Number of plants	Source	$2n$ chromosome number	Number of plants	Source	$2n$ chromosome number
2	Sault Ste. Marie	38	1	Lake Dore	47
1	Sault Ste. Marie	39	1	Lake Dore	48
1	Sault Ste. Marie	40	1	Lake Dore	50
3	Sault Ste. Marie	41	1	Owen Sound	52

It is apparent, then, that a field of sowthistles may contain a very mixed population. This population may have the 2 species, F_1 hybrids, backcrosses, and hybrid intercrosses. The situation becomes so complicated in a field that it is impossible to distinguish with any accuracy *S. arvensis* from the hybrids.

ACKNOWLEDGEMENTS

The field work for this study was assisted by a scholarship from the Research Council of Ontario. The authors wish to express their sincere thanks to R. T. Riddell for his direction in the cytological studies during the investigations, and for his many helpful suggestions throughout the work.

Appreciation is also expressed to the curators of the herbaria mentioned under "Materials and Methods".

REFERENCES

1. Bieberstein, Marschall v. Flora Taurico-Caucasica 2 : 238. 1808.
2. Erlandsson, S. (Bei A. u. D. Löve). In G. Tischler, Die Chromosomenzahlen der Gefasspflanzen Mitteleuropas. W. Junk, 's-Gravenhage. 1950.
3. Fernald, M. L. Gray's Manual of botany. American Book Co., New York, N.Y. 1950.
4. Fernald, M. L., and K. M. Wiegand. A summer's botanizing in eastern Maine and western New Brunswick. Rhodora 12 : 101-146. 1910.
5. Gleason, H. A. The new Britton and Brown Illustrated flora. New York Bot. Garden, New York, N.Y. 1952.
6. Groh, H. Perennial sowthistle and its smooth variety in Canada. Sci. Agr. 23 : 127-130. 1942.
7. Grun, Paul. Variations in the meiosis of alfalfa. Am. J. Bot. 38 : 475-482. 1951.
8. Hallier, E. W. J. D. Koch's Syn. der Deutsch. und Schweiz. Flora. ed. III. Leipzig. 1902.
9. Hayek, A. Prod. Florae Peninsulae Balcanicae. II. Dahlem, bei Berlin. 1928.
10. Hegi, Gustav. Illustrierte Flora von Mittel-Europa. VI-2. J. F. Lehmanns, Munich. 1929.
11. Löve, A., and D. Löve. Cytotaxonomical conspectus of the Icelandic flora. Acta Horti Gotoburgensis. (*In press*). 1955.
12. Sakisaka, M. Critical considerations of chromosome numbers in relation to plant habit (life forms). Proc. 7th Int. Bot. Congr., Stockholm, pp. 286-287. 1950.
13. Small, J. K. Another *Sonchus* for America. Torreya 21 : 100-101. 1921.
14. Stebbins, G. L., J. A. Jenkins, and M. S. Walters. Chromosomes and phylogeny in the Compositae; tribe Cichorieae. Univ. Calif. Publ. Bot. 26 : 401-430. 1953.
15. Wulff, H. D. Chromosomenstudien an der Schleswig-holsteinishen Angiospermen Flora, I, Deutsch. Bot. Ges., Berlin, 55 : 262-269. 1937.

IMPORTANCE OF THE SWEETCLOVER WEEVIL IN SPREAD OF SWEET CLOVER ROOT ROT IN SOUTHWESTERN ONTARIO[1]

K. G. Davey[2]

Entomology Laboratory, Chatham, Ontario

[Received for publication September 23, 1955]

ABSTRACT

Phytophthora cactorum (Leb. and Cohn.) Shroet., the organism causing root rot in sweet clover, was isolated from the surface of larvae of the sweet-clover weevil, *Sitona cylindricollis* Fahr., taken from the field. The fungus was not readily isolated from pupae and newly emerged adults. Lesions at the edges of larval feeding scars on the roots readily yielded isolates of the fungus. Laboratory experiments involving artificially cultured, aseptic sweet clover roots and aseptic first-instar weevil larvae demonstrated that the larvae can transmit the disease. The life-history of the weevil and the time of appearance of the disease symptoms suggest that the larvae may be of importance in spreading the disease, either by acting as vectors or by providing points of entry for the fungus.

INTRODUCTION

Failures of second-year stands of sweet clover in southwestern Ontario have been attributed in part to a root rot caused by the fungus *Phytophthora cactorum* (Leb. and Cohn). Shroet. (1, 8.) The importance of the adult of the sweetclover weevil, *Sitona cylindricollis* Fahr., as a defoliator of seedling stands has been recognized for some time (4). The larvae of this species, root feeders, have not been demonstrated to be important pests of sweet clover. A possible relationship between an insect and the disease was noted by Benedict (1) when he pointed out that disease lesions were commonly found adjacent to scars caused by the feeding of the larvae of the clover root curculio, *Sitona hispidula* (F.).

This is a report on an investigation of the relation between the sweet-clover weevil and the root rot organism *P. cactorum*. *S. hispidula* was not included in the study because this species made up less than 1 per cent of adults of *Sitona* spp. collected in 1954.

MATERIALS AND METHODS

As suggested by Benedict (1), the fungus was isolated on corn meal agar plates. After incubation for 3 days at room temperature, the plates were examined and any white fungal growths that exhibited the stiff angular branching characteristic of the genus *Phytophthora* were isolated on slants of potato dextrose agar. Isolates that exhibited oogonia and paragynous antheridia after culture on potato dextrose agar and that produced strongly papillate sporangia 36 to 48 hours after being placed in distilled water were taken as *P. cactorum* (3).

Isolates were made from insects taken from an infected field and one apparently uninfected. In the former case, 135 larvae, 12 pupae, and 28 newly emerged adults were smeared on the plates. In the latter, 12 larvae were squashed and smeared on the surface of the plates. In isolates from the infected field, 87 larvae were squashed and smeared on plates, 26 were

[1] Contribution No. 3356, Entomology Division, Science Service, Department of Agriculture, Ottawa, Canada.

[2] Assistant Entomologist.

surface-sterilized with 10 per cent Javex* (active ingredient: sodium hypochlorite) before smearing, and 22 were touched to the plates without breaking the cuticle.

To procure aseptic roots of sweet clover on which to perform transfer experiments, the roots were grown from seeds by artificial tissue culture. The nutrient medium, consisting of an agar base containing various inorganic and organic materials and 0·01 mg. per litre of naphthalene acetic acid, was modified slightly after Hildebrandt and Riker (6). Sweet clover seeds, sterilized by immersion for 10 minutes in 10 per cent Javex, were placed in tubes of the nutrient agar. After the seeds had germinated, the roots were transferred to nutrient in 50-ml. Erlenmeyer flasks. The cultures were transferred weekly until, after 4 to 6 weeks, the roots were large enough for the experiment. Cultures of parts of roots were usually unsuitable because of slow growth. All transfers were carried out in a sealed transfer chamber modelled after one described by Reyniers (7). Before use the chamber was swabbed with disinfectant and the interior was exposed to ultra-violet radiation for 24 hours.

Sweetclover weevil eggs, obtained from females brought into the laboratory, were surface-sterilized in 10 per cent Javex for 10 minutes and transferred to petri dishes containing agar. The eggs hatched in 7 to 10 days and the first-instar larvae were used in the transfer experiments. The egg cultures were examined periodically and any contaminated with bacteria or fungi were discarded.

Experiments concerning the transfer of the disease by the insect were carried out within the sealed transfer chamber. A root was removed from its nutrient and placed in a sterile petri dish containing several layers of moist filter paper. Three aseptic larvae were placed on each root. Inoculation of each root was effected by placing a drop of a water culture in a small incision in the root. After 5 days, 1 of the 3 larvae from each petri dish was transferred to a fresh aseptic root. Only 1 of the larvae was used because of the difficulty encountered in recovering the small insects from the roots. Sixty such attempts to demonstrate the transfer of the disease by the insect were made. Nineteen were incomplete. Of the remaining 41, 17 were made with larvae surface sterilized with 10 per cent Javex before transfer.

RESULTS

All 12 attempts to isolate the fungus from larvae taken from an uninfected field were unsuccessful.

Of the 12 pupae from an infected field smeared on the surfaces of corn meal agar plates, only 1 yielded a culture of *P. cactorum*. Twenty-eight newly emerged adults were similarly treated but no isolates of *P. cactorum* were obtained.

Of the 87 larvae that were squashed and smeared on plates, 29, or 33 per cent, yielded cultures of *P. cactorum*. On the other hand, only 3, or 11 per cent, of the 26 larvae which were surface-sterilized before smearing yielded *P. cactorum*. Nine of the 22 (i.e. 41 per cent) larvae touched to the plates without breaking the cuticle yielded active cultures of *P. cactorum*.

P. cactorum was readily isolated from the edges of larval feeding scars on sweet clover roots from the field. Disease lesions were often found adjacent to the feeding scars.

* Standard Chemical Co. Ltd., Toronto, Canada.

In transfer experiments in the sealed chamber, only 2 of the 17 surface-sterilized larvae transmitted the disease to new roots. Of the 24 larvae not surface-sterilized, 22 transmitted the disease.

DISCUSSION

The isolations of *P. cactorum* from larvae indicated that the disease organism is associated with the larvae of the sweetclover weevil. The fungus apparently occurs most frequently on the surface of the insect, although some surface-sterilized larvae yielded cultures of *P. cactorum*. It is also apparent that the fungus was carried on the cuticle of the larvae used in the laboratory experiments.

Although the larvae were demonstrated to transmit the disease under laboratory conditions, they may not transmit it in the field. The extent to which the larvae can be vectors depends, in part, on the degree to which they move from plant to plant. No data are available concerning such movements, but in a dense stand of sweet clover a slight horizontal movement would be sufficient for larvae to move from one root to another. There is no evidence, however, that the larvae cause the initial infection. Any part played by the larvae presupposes the presence of the organism in the field.

The association of disease lesions with the larval feeding scars, and the ease with which the organism was isolated from them, suggest that the wounds are important as portals of infection.

Although Herron (5) did not find weevil larvae in the field before May 6, third-instar larvae were numerous at this time at Chatham, Ontario. Since oviposition occurs in the field at least as early as mid March in Ohio, larvae are probably present by the end of March. A similar life-history has been noted in the field by Bird (2). Slykhius (8) has pointed out that disease symptoms are not prevalent until late April. There is, therefore, ample time for the larvae to wound the plants and provide access for the fungus.

ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of W. G. Benedict, Science Service Laboratory, Harrow, Ont., for guidance in identifying the fungus. Miss G. J. Bellinger, formerly of the Chatham Laboratory, suggested the use of artificial root culture.

REFERENCES

1. Benedict, W. G. Studies on sweet clover failure in southwestern Ontario. Can. J. Bot. 32: 82-94. 1954.
2. Bird, R. D. The sweetclover weevil, *Sitona cylindricollis* Fahr. Can. Ent. 79: 5-11. 1947.
3. Blackwell, E. The life-history of *Phytophthora cactorum*. Br. Mycol. Soc. Trans. 26: 71-89. 1943.
4. Caesar, L. Notes on a new or hitherto unrecorded pest of sweet clover in Ontario. 66th Ann. Rept. Ent. Soc. Ontario, 1934, pp. 54-56. 1935.
5. Herron, J. C. Biology of the sweetclover weevil and notes on the biology of the clover root curculio. Ohio J. Sci. 53: 105-112. 1953.
6. Hildebrandt, A. C., and A. J. Riker. Influence of some growth regulating substances on sunflower and tobacco tissue *in vitro*. Am. J. Bot. 34: 421-427. 1947.
7. Reyniers, J. A. Micrurgical and germ free methods. 1st ed. C. C. Thomas, Springfield, Ill. 1943.
8. Slykhius, J. T. Investigations on sweet clover failure in southwestern Ontario. Sci. Agr. 32: 1-18. 1951.